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Regulatory Impact Analysis of the National Ambient Air Quality Standards for Nitrogen Dioxide

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16. ABSTRACT

This report examines the costs, benefits, and other economic impacts of implementing alternative primary annual nitrogen dioxide (NO_2) ambient air quality standards (NAAQSs). Three alternative NAAQSs are investigated: 0.053 ppm, the current air standard, 0.060 ppm, and 0.070 ppm. Results are provided for two mobile source inspection and maintenance scenarios and for three automotive air pollution control standards. Also discussed is the health evidence and other environmental effects evidence that support both a primary and secondary (welfare) NAAQS being established at the same level.

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Regulatory Impact Analysis of the National Ambient Air Quality Standards for Nitrogen Dioxide

U.S. Environmental Protection Agency
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Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

June 1985

A draft regulatory impact analysis (RIA) was reviewed by the Office of Management and Budget (OMB) and by the Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency (EPA) and released to the public at the time of proposal. This final RIA was reviewed within EPA and by OMB and is being published in conjunction with retention of the nitrogen dioxide national ambient air quality standards. Please address any questions on the RIA to Thomas McCurdy (919-541-5655) or David McLamb (919-541-5611), MD-12, U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711.

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I. INTRODUCTION

This final Regulatory Impact Analysis (RIA) of the nitrogen dioxide (NO_2) national ambient air quality standards (NAAQS) has been prepared in accordance with Executive Order 12291, which requires that an RIA be done for every rule that may result in an annual impact of $100 million or more on the economy.

As provided for in sections 108 and 109 of the Clean Air Act as amended, EPA has reviewed and revised the criteria upon which the existing primary (to protect public health) and secondary (to protect public welfare) standards are based. The existing primary and secondary standards for NO_2 are both currently set at 0.053 ppm (100 $\mu g/m^3$) as an annual arithmetic average. As a result of the review and revision of the health and welfare criteria, EPA proposed to reaffirm the existing annual average standards and specifically requested comment on whether a separate short-term (less than 3 hours) standard is needed to protect public health (49 FR 6866).

The Clean Air Act specifically requires that primary and secondary NAAQS be based on scientific criteria relating to the level(s) that should be attained to protect public health and welfare adequately. EPA and the courts interpret the Act as precluding consideration of the cost or feasibility of achieving such standards in determining the level of the ambient standards. In response to Executive Order 12291, EPA has prepared a regulatory impact analysis (RIA). However, EPA has not considered the results of this RIA in selecting the final standards.

This RIA examines the benefits, costs, and other economic impacts of alternative primary NO_2 standards on both the public and private sectors. In specifying some aspects of the alternatives to be analyzed, EPA relied heavily on the document Review of the National Ambient Air Quality Standards for Nitrogen Oxides: Assessment of Scientific and Technical Information

(NO_2 Staff Paper, EPA, 1982). The NO_2 Staff Paper interprets the relevant scientific and technical information reviewed in the revised Air Quality Criteria for Nitrogen Oxides (Criteria Document, EPA, 1983). The NO_2 Staff Paper, which has undergone careful review by the Clean Air Scientific Advisory Committee (an independent advisory group) and the public, serves to identify those conclusions and uncertainties in the available scientific literature that should be considered in selecting the form, level, and averaging times of the primary and secondary standards for NO_2.

II. STATEMENT OF NEEDS AND CONSEQUENCES

This chapter of the RIA summarizes the statutory requirements affecting the development and revision of NAAQS and briefly describes the nature of the ambient NO_2 problem. The need for regulatory action and the consequences of the regulation in terms of improving the functioning of the market are also discussed.

A. LEGISLATIVE REQUIREMENTS AFFECTING DEVELOPMENT AND REVISION OF NAAQS

Two sections of the Clean Air Act govern the establishment and revision of NAAQS. First, as a preliminary step in developing standards, section 108 (42 U.S.C. § 7408) directs the Administrator to identify all pollutants which may reasonably be anticipated to endanger public health or welfare and to issue air quality criteria for such pollutants. Such air quality criteria are to reflect the latest scientific information useful in indicating the kind and extent of all identifiable effects on public health or welfare that may be expected from the presence of the pollutant in the ambient air. Section 109(d) of the Act (42 U.S.C. § 7409(d)) requires the Administrator to propose and promulgate primary ambient air quality standards, based on the section 108 criteria and allowing an adequate margin of safety.

Section 109(d) of the Act (42 U.S.C. § 7409(d)) requires periodic review and, if appropriate, revision of existing criteria and standards. If, in the Administrator's judgment, the Agency's review and revision of criteria make appropriate the proposal of new or revised standards, such standards are to be revised and promulgated in accordance with section 109(b). Alternatively, the Administrator may find that revision of the standard is not appropriate and conclude the review by reaffirming the existing standards. In addition, section 109(c) specifically requires the Administrator to promulgate a primary standard for NO_2 with an averaging time of not more than 3 hours unless he finds no significant evidence that such a short-term standard is required to protect public health.

Section 109(b)(1) defines the primary standard as that ambient air quality standard the attainment and maintenance of which in the judgment of the Administrator, based on the criteria and allowing an adequate margin of safety, is requisite to protect the public health. The secondary standard, as defined in section 109(b)(2), must specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator, based on the criteria, is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. Welfare effects are defined in section 302(h) (42 U.S.C. § 7602(h)) and include effects on soils, water, crops, vegetation, man-made materials, animals, weather, visibility, hazards to transportation, economic values, personal comfort and well-being, and similar factors.

The Act, its legislative history, as well as recent judicial decisions (Lead Industries Association, Inc. v. EPA, 1980; American Petroleum Institute v. EPA, 1981) make clear that the costs and technological feasibility of attainment are not to be considered in setting primary or secondary NAAQS. Such factors can be considered to a degree in the development of state plans to implement such standards. Under section 110 of the Act, the States are to submit to EPA for approval State Implementation Plans (SIPs) that provide for the attainment and maintenance of NAAQS by certain deadlines.

Finally, section 109(d) of the Act directs the Administrator to periodically review all existing NAAQS and criteria and revise them as necessary.

B. NATURE OF THE NITROGEN DIOXIDE PROBLEM

NO_2 is an air pollutant generated by the oxidation of nitric oxide (NO), which is emitted from both mobile and stationary sources. At elevated concentrations NO_2 can adversely affect human health, vegetation, materials, and visibility. Nitrogen oxide compounds (NO_x) also contribute to increased rates of acidic deposition. Typical long-term ambient concentrations of NO_2 range from 0.001 ppm in isolated rural areas to a maximum annual concentration of approximately 0.06 ppm in one of the nation's most populated urban areas. Short-term hourly peak concentrations rarely exceed 0.5 ppm.

A variety of respiratory system effects have been reported to be associated with exposure to NO_2 concentrations less than 2.0 ppm in humans and animals. The most frequent and significant NO_2-induced respiratory effects reported in the scientific literature at the time the Criteria Document and OAQPS Staff Paper were published include: (1) altered lung function and symptomatic effects observed in controlled human exposure studies and in community epidemiological studies, (2) increased prevalence of acute respiratory illness and symptoms observed in outdoor community epidemiological studies and in indoor community epidemiological studies comparing residents of gas and electric stove homes, and (3) lung tissue damage and increased susceptibility to infection observed in animal toxicology studies. As the Criteria Document concludes, results from these several kinds of studies collectively provide evidence indicating that certain human health effects may occur as a result of exposures to NO_2 concentrations at or approaching recorded ambient NO_2 levels.

Only one urban area exceeded the NAAQS in 1982. By 1985, we expect that all urban areas in the country will be able to maintain the existing 0.053 ppm NO_2 NAAQS except for this one urban area -- even without adding new pollution control systems. Thus NO_2 pollution is not now, nor will it be in the near future, an extensive problem. It should be noted, however, that predictions of attainment status depend upon a number of factors and analytic assumptions including the effectiveness of emission control systems, particularly those used on private automobiles; the effectiveness of inspection and maintenance (I&M) programs; the growth in vehicle miles travelled in urban areas; the growth and mix of industrial sources of NO_x emissions; and the actual air quality levels monitored once all monitors meet EPA's siting, instrumentation, and quality assurance criteria.

The net annualized cost, after energy savings are considered, of implementing reasonably available NO_x mobile and stationary source controls to meet the existing 0.053 ppm annual standard in 1985 will amount to $130-140 million (see Tables 5.1 and 5.3). These expenditures will, depending on assumptions regarding federal motor vehicle control program (FMVCP) standards and use of I&M programs, bring all but one urbanized area of the country into attainment. These costs are in addition to approximately $1,610-1,910 million per year required for the NO_x portion of the FMVCP, and in addition to almost $110 million per year incurred by industry to meet NO_x new source performance standards (NSPS). FMVCP and NSPS expenditures are not directly related to a NO_2 NAAQS, so do not vary with the alternative ambient standards investigated. (All cost estimates are in constant 1984 dollars.)

If attainment is delayed until 1990, annualized NO_x control expenditures directly related to the NO_2 annual NAAQS drop and all areas attain the

0.053 ppm NAAQS. The net annualized cost of instituting reasonably available controls in 1990 are estimated to range between $0-100 million in constant 1984 dollars. However, the non-NAAQS related additional FMVCP and NSPS costs are estimated to be higher because of additional control equipment required for the NSPS and FMVCP programs for 1990. Annualized 1990 costs for FMVCP and NSPS are estimated to be $2,640-4,470 and $250 million, respectively.

A draft environmental impact statement (EIS) indicates that controlling NO_x emissions may result in biological, ecosystem, and esthetic benefits (EPA, 1982d). NO_x controls will lower ambient nitrosamine concentrations and reduce nitrate-based acid precipitation. In urban areas with a high ratio of non-methane organic compounds-to-NO_x concentrations, reducing NO_x emissions should reduce peak ozone levels. However, in urban areas with a low ratio, reducing NO_x emissions without simultaneously reducing non-methane organic emissions may lead to higher peak ozone concentrations downwind of major urban areas.

C. NEED FOR REGULATORY ACTION

To reiterate, NO_2 pollution imposes a cost on society in the form of health effects and welfare losses. Unless polluters are forced to pay the full cost of degrading the air, they will use more of the resource (the assimilative capacity of the air) than is economically efficient. In this respect, the market for air resources is said to fail.

As will be stated in the next section, non-regulatory approaches to rectify this problem, while attractive in theory, are deficient in practice. Voluntary solutions such as negotiations and subsidies do not guarantee desired results and may in fact exacerbate the pollution problem. Other market-oriented schemes are not presently allowed by the Clean Air Act.

The need for some control action has been demonstrated and the legal authority for such action has been established by the Clean Air Act. It is felt that only through government regulation will the appropriate steps be taken.

III. ALTERNATIVES EXAMINED

This chapter briefly presents potential alternatives to the proposed retention of the current NO_2 NAAQS. The outline for the section is adopted from Executive Order 12291 which requires that at a minimum the following alternatives be examined:

a) No regulation

b) Regulations beyond the scope of present legislation

c) Alternate stringency levels and implementation schedules

d) Market oriented alternatives

Although Executive Order 12291 requires that all alternatives be examined, only the most promising ones need be analyzed in detail.

A. NO REGULATION

The option of no regulation could be considered a baseline, against which the incremental benefits and costs of all abatement actions could be compared. This option would essentially leave it up to the damaged parties to negotiate or litigate a settlement for compensation or greater pollution control. Realistically, however, there is little or no incentive for a company to negotiate with individuals to reduce NO_x emissions since, without similar activity by its competitors, the company would be put at a singular disadvantage. Likewise, litigation is not a viable course for individuals due to the likely high costs of proving damages and the reluctance of "free riders" to join class actions.

Given the unlikely success of these approaches in achieving a socially desirable result, the option of no regulation is not considered an acceptable option and therefore has not been analyzed further.

B. OTHER REGULATORY APPROACHES

Other regulatory approaches include such options as technology based emission standards and regional air quality standards. Technology based emission standards are required by the present law in a variety of forms (e.g. new source performance standards (NSPS) for new and modified sources, motor vehicle standards, lowest achievable emission rate (LAER) and reasonably available control technology (RACT) in non-attainment areas. They typically specify allowable emission rates for specific source categories, based on technological feasibility, and are designed to accelerate attainment of the air quality standards. The LAER and RACT provisions enable economic growth in non-attainment areas, while encouraging progress toward attainment. NSPS and motor vehicle standards help to reduce future pollution problems by controlling all new sources.

Although performance and technology based standards are useful in achieving air quality goals, they cannot substitute for ambient standards since they are not based on health criteria and cannot guarantee that society's health objectives will be met. For example, these standards do not account for local meteorology or the interaction of multiple sources which could have dramatic effects on air quality.

Differences in terrain and meteorology as well as regional differences in valuing clean air have been cited as reasons for adopting regional air quality standards. This approach has not garnered serious attention because it would require legislative change. Furthermore, there are other objections. Differences in terrain and meteorology can and are being considered in the setting of SIP limits. The grave problems of long range pollutant transport may compromise the effectiveness and equity of a system of regional standards. Also, regional valuations of air quality ignore the significance of the "existence" and "option" values of environmental amenities. For example, a resident of New York City might place value on knowing that air quality in the Grand Canyon is being protected because it is an important part of the Country's heritage or because he may opt to visit the Grand Canyon some day and would like the air to be pristine.

Thus, because the use of these regulatory approaches alone is not permitted by the present legislation and because they do not respond to prevailing legislative interest, they are not considered viable substitutes for the NAAQS and are not analyzed further.

C. REGULATORY ALTERNATIVES WITHIN THE SCOPE OF PRESENT LEGISLATION

EPA believes the cumulative evidence from animal, controlled human exposure, and community indoor air pollution studies strongly suggests that NO_2 may cause adverse health effects in sensitive population groups exposed to NO_2 at or near existing ambient levels. However, given the uncertainties existing in the available scientific data, no rigorous rationale can be offered to support a specific NO_2 standard.

Two approaches to limit potential health effects associated with NO_2 exposure in the ambient air have been considered. The first is to retain an annual standard at a level between 0.05 ppm and 0.08 ppm to protect against short-term peak and chronic long-term exposures. A 0.08 ppm standard would be expected to limit the number of days with hourly peak concentrations above 0.30 ppm to about ten per year based on an analysis of existing ambient air quality data. In most areas of the country attainment of an annual standard of 0.05 ppm should limit the occurrence of 0.30 ppm peaks and limit hourly concentrations of greater than 0.15 ppm to a range of approximately 10-20 days (some southern California sites may exceed 0.15 ppm on as many as 40 days). Results from several indoor epidemiology studies suggest that exposure to repeated peaks up to 0.5-1.0 ppm and possibly as low as 0.15 to 0.30 may be of concern for children.

An annual standard in this range also would provide reasonable assurance that 1-hour peak concentrations of NO_2 would not exceed 0.5 ppm, the level at which mild symptomatic effects have been observed in asthmatics. An alternative approach is to establish a new multiple exceedance 1-hour average NO_2 standard at a level below 0.5 ppm. Such a standard acknowledges medical evidence suggesting the importance of repeated peak exposures and would incorporate an allowable rate of exceedance set at a value which would depend on the standard level.

Either approach can provide a reasonable degree of protection against repeated peak exposures in the range of 0.15 to 0.30 ppm. A long-term standard offers the practical advantage of not requiring formulation and implementation of a new regulatory program. Establishing a new short-term standard would require more significant changes in modeling and monitoring procedures than retention of an annual standard.

D. MARKET-ORIENTED ALTERNATIVES

There are several market-oriented approaches which can be considered as theoretical alternatives to achieve the NAAQS for NO_2, none of which are contemplated by the Clean Air Act. These approaches include pollution charges, marketable permits, and subsidies and are briefly discussed below.

Charges. This policy places a charge (or tax) on each unit of a pollutant emitted. Firms presumably would choose an abatement strategy which minimizes their total control cost, including the pollution charge. Since the charge is uniform, each polluter would control his emissions until his marginal cost of abatement is equal to the pollution charge. One difficulty with this strategy is choosing the appropriate charge level that will lead to the desired air quality.

Permits. In this policy the regulatory agency places a limit on the amount of emissions that may be released into a particular region over a specific time period. The Agency then issues and distributes discharge permits, allowing the holders to emit the amount of pollution specified by the permits. (The sum of the discharges allowed by the permits is equal to the emissions cap for the region.) These permits would be fully transferable so that a market for these rights would develop. Since the price of the discharge permit could fluctuate fully, the permits would be alloted efficiently, with those with the highest marginal control costs bidding the highest prices.

Subsidies. A subsidy system pays sources for each unit of pollution that they do not emit. The subsidies can take various forms including lump sum payments, tax and depreciation credits, and low interest loans. In some minor cases, with a small number of participants, a subsidy system may produce the desired environmental result. But, by its nature, a subsidy system invites polluters to pollute heavily, or just threaten to do so in order to enhance the subsidy. In addition, by making the polluting activity more profitable and encouraging additional firms to enter the industry, a subsidy system can actually increase total emissions even though emissions per polluter may be decreased.

Summary. Although the Clean Air Act allows States to use market-oriented approaches in attaining air quality standards, they are not legal alternatives to national ambient standards and therefore are not analyzed further.

IV. ASSESSING BENEFITS

A. ASSESSING BENEFITS OF AIR POLLUTION CONTROL

The benefits of air pollution control are the values (both known and unknown) to society brought about by reducing the health and welfare effects caused by pollution. The translation of impacts into dollar values, where possible, allows the summation of impacts and direct comparison with the costs of pollution control. Estimating the benefits of air pollution control requires an understanding of how changes in pollution emissions affect atmospheric conditions and thereby affect people's health and welfare, and how these effects are valued. These links are illustrated in Figure 4.1.

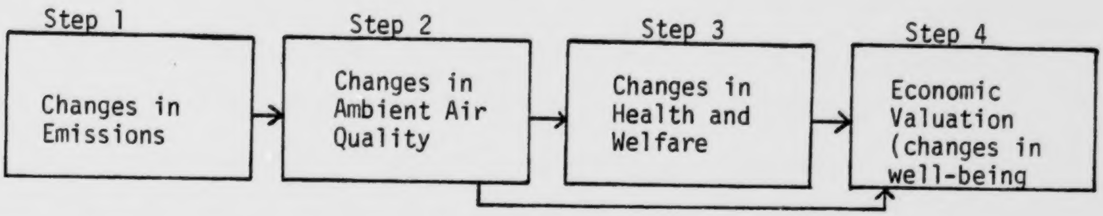
Step 1
Changes in Emissions
Step 2
Changes in Ambient Air Quality
Step 3
Changes in Health and Welfare
Step 4
Economic Valuation (changes in well-being

Figure 4.1

STEPS IN MEASURING BENEFITS

The Clean Air Act is designed to prevent adverse effects, such as:

1. Health

adverse impacts to human health--acute or chronic effects that result in increased mortality or morbidity.

2. Welfare

    a. adverse impacts to materials--corrosion, soiling and other damage to building materials, metals, fabrics, equipment, etc.

    b. adverse impacts to vegetation--reduction in productivity or aesthetic appeal of domestic crops, ornamental plants

    c. adverse impacts to animals--effects on health and productivity of livestock, pets, and wildlife.

    d. adverse impacts on climate--changes in temperatures and/or precipitation.

    e. adverse aesthetic impacts--reduced visibility or visual discoloration of the air and objects viewed through it and other aesthetic effects such as unpleasant odors.

These impacts on well-being, including the risks of incurring them and the costs of avoiding or ameliorating them, determine the economic value of the changes in air quality.[1]

Thus, the appropriate measure of the benefits of pollution control will reflect the sum of the values assigned to improvements in air quality by all individuals directly or indirectly affected. These benefits are often classified into three categories--user, option, and existence values. User values are the benefits of improved air quality that the individual expects to enjoy directly. Option values result from uncertainty concerning future demand for air quality. Existence values result from the mere knowledge that certain environmental conditions prevail even though the individual may never experience them himself.

The approach used to estimate environmental benefits is derived from economic welfare theory. The benefits of a change in air quality are said to be equal to the change in well-being, or "utility", that results. Such a change in utility is difficult to quantify. One technique is to measure the maximum amount the individual is willing to pay (WTP) in order to obtain a certain level of environmental quality. A slightly different measure than WTP for the benefits of a change in air pollution is the willingness to accept compensation (WTA) in return for incurring an increase in air pollution or foregoing a decrease in air pollution. The WTP measure presumes that an individual does not have a predetermined right to any particular level of air quality, in which case the point of reference is the lower level of air quality. The WTA measure presumes that the appropriate point of reference is the improved level of air quality. Since Section 109 of the Clean Air Act authorizes EPA to protect the public from adverse health and welfare effects of air pollution, it may be argued that WTA is the appropriate benefit measure.

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[1] In order to avoid confusion, the term "costs" will refer to the costs of pollution control while the term "damages" will refer to the adverse effects of pollution.

It is important to note that changes in air quality will affect people over time. The benefits that accrue to these people must be discounted to a standard time period to be validly compared with total pollution control costs. The effects of differences in income levels on benefit values and the distribution of benefits are non-trivial concerns that can be incorporated in the benefits analysis.

B. ESTIMATING BENEFITS ASSOCIATED WITH ALTERNATIVE NO_2 NAAQS

As a result of project time constraints and uncertainties regarding the effects of NO_2 exposure on health, vegetation, visibility and other welfare measures (see Section II), EPA's approach to estimating the benefits of NO_2 control focuses on the reductions in the concentration of NO_2 that are obtained under different NO_2 standards. This information is combined with cost data to estimate the incremental costs per PPM reduction. The following sections discuss the mechanisms of toxicity, nature of the effects and sensitive population groups.

1. Mechanisms of Toxicity and Nature of Effects

The mechanisms of toxicity responsible for effects caused by short-term and long-term exposures to NO_2 are incompletely understood. The variety of effects, such as (1) increased airway resistance and alterations in lung hormone metabolism for short-term exposures and (2) increased susceptibility to infection and morphological damage for long-term or multiple exposures, may well be explained by related mechanisms of oxidative damage. Because NO_2 is relatively insoluble in water, some fraction normally penetrates to the distal airways during inhalation. However, the reactivity of NO_2 is sufficient to permit chemical interaction and absorption along the entire tracheobronchial tree.

When NO_2 enters the lungs, most of the reacting NO_2 rapidly oxidizes cellular lipids, although some slowly hydrolyzes to form HNO_2 and HNO_3. The most destructive reaction involves oxidation of unsaturated lipids of the cellular membrane and results in the formation of peroxidic products. The disruption of the cellular membrane, which is essential for maintaining cellular integrity and function, probably accounts for many of the biological effects (e.g., hyperplasia, morphological damage, pulmonary edema) which have been ascribed to NO_2.

Nature of Health Effects. The OAQPS Staff Paper (EPA, 1982a) presents a detailed and comprehensive assessment by EPA staff of the key health effect studies contained in the Criteria Document and other critical scientific issues relevant to the review of the existing annual NO_2 standard and the need, if any, for a separate short-term (less than 3 hours) NO_2 standard. This assessment is summarized in the proposal preamble (49 FR 6866) and draft NO_2 RIA.

A variety of respiratory system effects have been reported to be associated with exposure to short- and long-term NO_2 concentrations less than 2.0 ppm in humans and animals. The most frequent and significant NO_2-induced respiratory effects reported in the scientific literature at the time the Criteria Document and OAQPS Staff Paper were published include: (1) altered lung function and symptomatic effects observed in controlled human exposure studies and in community epidemiological studies, (2) increased prevalence of acute respiratory illness and symptoms observed in outdoor community epidemiological studies and in indoor community epidemiological studies comparing residents of gas and electric stove homes, and (3) lung tissue damage, development of emphysema-like lesions in the lung, and increased susceptibility to infection observed in animal toxicology studies. As the Criteria Document concludes, results from these several kinds of studies collectively provide evidence indicating that certain human health effects may occur as a result of exposures to NO_2 concentrations at or approaching recorded ambient NO_2 levels.

At the time of proposal, based on controlled human exposure studies, EPA concluded that human pulmonary function effects of clear health concern resulting from single, short-term exposures of less than 3 hours duration have been unambiguously demonstrated only at concentrations (greater than 1.0 ppm) well in excess of ambient exposure levels typically encountered by the public. More subtle health effects that were of uncertain health significance, such as mild symptomatic effects, had been reported for some asthmatics after a single 2-hour exposure to 0.5 ppm.

The principal evidence reviewed in the OAQPS Staff Paper and proposal on the effects of repeated short-term exposures came from a series of cross-sectional epidemiological (community) studies, some ongoing, which reported increased prevalence of acute respiratory illness and impaired lung function in children living in homes with gas stoves (a source of NO_2) as compared to children living in electric stove homes. Findings from several animal studies demonstrating reduced resistance to infection due to NO_2 exposures support the belief that NO_2 exposures are probably related to the effects observed in these indoor epidemiological studies. A limitation of these studies with respect to setting an NO_2 NAAQS is that the investigators did not measure short-term NO_2 concentrations in the homes of the subjects in the indoor epidemiology studies. Based on NO_2 monitoring data from other gas stove homes, EPA staff estimated that the health effects observed in gas stove homes, if due to NO_2 exposure, were likely to be associated with frequent, repeated short-term peak exposures to NO_2 levels ranging up to 0.5 to 1.0 ppm and possibly as low as 0.15 to 0.30 ppm.

Findings from several animal studies, such as development of emphysema-like lesions and increased susceptibility to infection, indicated at the time of proposal that long-term exposures to elevated NO_2 concentrations can lead to serious adverse health effects in animals. A major limitation in making quantitative use of these studies was the lack of satisfactory methods for directly extrapolating the results to effect levels in humans.

Since proposal, EPA's ECAO has reviewed the scientific studies that have become available since CASAC closure on the Criteria Document and OAQPS Staff Paper and that were identified by EPA staff and/or in public comments on the NO_2 proposal. This review was submitted to the CASAC and was discussed at a meeting held on July 19-20, 1984; a revised document (Grant, 1984) reflecting

CASAC and public comments has been placed in the public docket (OAQPS 78-9, IV-A-). It should be noted that a more complete scientific assessment of these studies is not possible at this time because many of the studies have yet to be published in the peer-reviewed scientific literature or appear only as abstracts. The principal points from ECAO's review of the new studies are summarized below.

(1) The more recent controlled human exposure studies (most of which are presently in unpublished form) present mixed and conflicting results concerning respiratory effects in asthmatics and healthy individuals at concentrations in the range of 0.1 to 4.0 ppm NO_2. Some new studies have reported an increased effect on airway resistance or lung function when challenged by a bronchoconstricting agent and NO_2 (Ahmed et al., 1982; Kleinman et al., 1983; Bauer et al., 1984) while other recent studies have reported no statistically significant effects from NO_2 alone or with a bronchoconstricting agent (Hazucha et al., 1983; Ahmed et al., 1983). It is not possible, at this time, to evaluate the reasons for these mixed results. Only Kagawa and Tsuru (1979) have reported results possibly suggestive of short-term NO_2 effects on pulmonary function without combined provocative challenge by other agents (e.g., carbachol or cold air) for a group of 6 subjects exposed to 0.15 ppm NO_2. However, the small size of the decrements reported (all less than 5 percent) in conjunction with questions regarding the statistical analyses used suggest caution in accepting the reported findings as demonstrating NO_2 effects on pulmonary function at 0.15 ppm, especially in view of the lack of confirmatory findings by other investigators at that exposure level.

(2) The most recent indoor epidemiological studies by the British and Harvard groups indicate somewhat weaker findings of an association between

NO_2 and respiratory effects than the original studies conducted by these groups cited in the Criteria Document and proposal notice. For example, an estimated odds ratio for respiratory illness before age 2 of 1.23 ($p < 0.01$) previously reported by the Harvard group (Speizer et al., 1980), has been reduced to 1.12 ($p = .07$) by the inclusion in the statistical analyses of data from additional children enrolled in the study (Ware et al., 1984). The association between residence in a gas stove home and respiratory illness before age 2 is, therefore, no longer statistically significant. Nonetheless, the Ware et al. study continued to find small statistically significant decreases in pulmonary function when the data for this large sample of children were analyzed.

The associations between use of gas stoves and increased respiratory illness before age 2 and the use of gas stoves and decreases in lung function levels in school age children were both reduced when the Harvard group controlled for parental education (Ware et al., 1984). More specifically, when an adjustment for parental education was included in the analysis, the odds ratio for respiratory illness before age 2 was reduced further to 1.11 ($p = 0.14$) and the decreases in lung function were 30 percent smaller and no longer statistically significant. Because level of parental education is negatively associated with the use of gas stoves and positively associated with respiratory illness and lung function level, the authors state that the adjustment for parental education "may represent confounding but may also represent overadjustment for a surrogate for gas stove use" (Ware et al., 1984).

Some other indoor epidemiological studies (with much smaller statistical power) involving electric and gas stove homes have reported statistically significant increased rates of symptoms and illness in residents of gas stove homes (Comstock et al., 1981; Helsing et al., 1982; Lebowitz et al., 1982), while other studies have failed to find any statistically significant associations with gas stove usage (Jones et al., 1982; Melia et al., 1982; Melia et al., 1983). Unfortunately, none of the recent studies has provided an assessment of short-term NO_2 levels in the residences of the subjects evaluated. Overall, then, the newly available data from indoor epidemiological studies do not appear to resolve the mixed results reported in earlier studies.

(3) The results from the more recent animal studies further substantiate the NO_2 effects on immune function and increased susceptibility to infection. However, the lack of an acceptable method at this time for quantitative extrapolation of the animal data to man greatly limits their usefulness beyond providing qualitative support for analogous effects plausibly being associated with repeated, short-term high-level and chronic exposure to NO_2.

2. Sensitive Population Groups

On the basis of the health effects evidence reviewed in the Criteria Document (EPA, 1983), EPA concludes that the following groups may be particularly sensitive to low-level NO_2 exposures: (1) young children, (2) asthmatics, (3) chronic bronchitics and (4) individuals with emphysema or other chronic respiratory diseases. In addition, there is reason to believe that persons with cirrhosis of the liver or other liver, hormonal, and blood disorders, or persons undergoing certain types of drug therapies may also be more sensitive to NO_2 based on the findings from animal studies showing increased systemic, hematological, and hormonal alterations after exposure to NO_2. Due to the lack of human experimental data for these latter groups, however, EPA is considering the potential effects on such persons only as a factor in providing an adequate margin of safety.

In EPA's judgment, the available health effects data identify young children and asthmatics as the groups at greatest risk from low-level, ambient exposures to NO_2. It has been estimated (U.S. Bureau of the Census, 1973) that in 1970, the total number of children under five years of age was 17,163,000 and between five and 13 years of age was 36,575,000. Data from the U.S. National Health Survey (HEW, 1973) for 1970 indicate that there were 6,526,000 chronic bronchitics, 6,031,000 chronic bronchitics, 6,031,000 asthmatics, and 1,313,000 emphysematics at the time of the Survey. Although there is overlap on the order of about one million persons for these three categories, it is estimated that over twelve million persons experienced these chronic respiratory conditions in the U.S. in 1970. Table 4.1 presents estimates of the size of the population groups which are most susceptible to presence of NO_2 in the atmosphere.

In regard to evidence for the secondary standard, NO_x effects on man's environment, personal comfort, and well-being include impacts on vegetation, materials, visibility, rates of acidic deposition, and symptomatic effects in humans. Because acidic deposition is an important and complex problem associated with multi-pollutant interactions, it is being addressed in a separate program by the Agency and has not been a specific element of the NO_2 standard review. Please refer to the section, Welfare Effects and the Secondary Standard in Chapter VII for further details.

TABLE 4.1

SUMMARY OF POTENTIALLY SENSITIVE POPULATION GROUPS

ensitive Group	Supporting Evidence	References for Supporting Evidence	Population Estimates
hildren	Children under age 2 exhibit increased prevalence of respiratory infection when living in homes with gas stoves. Children up to age 11 exhibited increased prevalence of respiratory infections when living in gas stove homes.	Speizer et al, 1980 Melia et al, 1979	age 0-5 17.2 million[a] age 5-13 36.6 million[a]
sthmatics	Asthmatics reacted to lower levels of NO_2 than normal subjects in controlled human exposure studies.	Kerr et al, 1979 Orehek et al, 1976	6.0 million[b]
hronic ronchitics	Chronic bronchitics reacted to low levels of NO_2 in controlled human exposure studies.	Kerr et al, 1979 Von Nieding et al, 1971 Von Nieding et al, 1970	6.5 million[b]
mphysematics	Emphysematics have significantly impaired respiratory systems. Because studies have shown that NO_2 impairs respiration by increasing airway resistance, it is reasonable to assume that emphysematics may be sensitive to NO_2.	Von Nieding et al, 1971 Beil and Ulmer, 1976 Orehek et al, 1976	1.3 million[b]
ersons with uberculosis, neumonia, leurisy, Hay ever or Other llergies	Studies have shown that NO_2 increases airway resistance. Persons who have or have had these conditions may be sufficiently impaired to be sensitive to low levels of NO_2.	Von Nieding et al, 1971 Beil and Ulmer, 1976 Orehek et al, 1976	unknown
ersons with iver, Blood r Hormonal isorders	NO_2 induces changes in liver drug metabolism, lung hormone metabolism, and blood biochemistry.	Menzel, 1980 Miller et al, 1980 Posin et al, 1979	unknown

U.S. Bureau of Census (1973).

U.S. Dept. of Health, Education, and Welfare (1973).

V. COST ANALYSIS

A. INTRODUCTION

This chapter emphasizes the direct principal, or real-resource, costs associated with controlling emission sources of nitrogen oxides (NO_x) air pollution in order to attain alternative nitrogen dioxide (NO_2) national ambient air quality standards. The costs discussed are for two years--1985 and 1990. The costs are in constant March 1984 dollars unless otherwise noted. Cost estimates are derived from an EPA report entitled Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT) (EPA, 1982c), as updated by Appendix B of this report.

The above report contains a number of detailed cost and economic analyses that are not reproduced here. These include an investigation of the impacts of setting alternative NO_2 standards on specific population income groups (all income categories), industrial sectors, local governments, and small businesses. Major findings from these specialized studies are:

1. no particular segment of the population is forced to pay a disproportionate amount of the total cost of mobile source control. Therefore, there are no significant adverse income distribution impacts associated with any of the alternative NO_2 standards. Repair costs resulting from an NO_2 inspection and maintenance program, however, are a higher percentage of income for low income groups than for middle and high income groups.
2. while "distressed cities" are definitely affected by various NO_2 control programs, the probable overall impact on local government finances is considered to be negligible. The prime

reason for this conclusion is that most of the direct costs of NO_2 control programs are borne by motor vehicle owners and users, not by local governments. Inspection and maintenance programs are self-supporting, paid for by user fees; transportation control measures are largely paid for by the federal government under a U.S. Department of Transportation program intended to reduce energy consumption associated with motor vehicle use.

3. small businesses are probably not adversely affected by an NO_2 control program. While a small number of NO_x emitting sources require controls to attain a 0.053 ppm NAAQS (172 out of the 29,000 that were investigated), none of the source categories affected contains many small businesses. The affected categories are oil and gas extraction (SIC 13), petroleum and coal products (SIC 29), primary metals (SIC 33), and public utilities (SIC 49).
4. financial capital is generally available for those relatively large industrial sources that need to install NO_x pollution control equipment, in the sense that major shifts are not anticipated in the firm's opportunity cost of capital. For all but one industrial category in the country, NO_x capital expenditures are less than 1% of projected capital expenditures. Even in that category, oil and natural gas extraction, NO_x capital expenditures are estimated to be only 1.5% of projected expenditures.
5. for affected industries and plants, controls associated with the alternative standards are judged to be economically

> affordable. No significant product output adjustments are anticipated in response to product price changes, which should be quite small for all alternative standards (less than 0.02% at most).

The interested reader is referred to the detailed report (EPA, 1982c) for more information on the items discussed above.

As discussed in the above reference, the methodology used to estimate regulatory impacts associated with alternative NO_2 standards is highly sensitive to the value used to represent air quality in the base year (the so-called design value). A small change in this value can substantially alter non-attainment area projections and the amount of control theoretically needed in a particular location. The NO_x control cost estimates are also greatly affected by the nature and timing of the program assumed for an area. In all cases, a cost effectiveness procedure was used to determine what mix of NO_x controls, such as inspection and maintenance (I&M) programs and transportation control measures (TCM), would be used in that area.

The control measures investigated in the NO_2 cost analysis were all "reasonably available," meaning that the techniques are currently operational and are expected to be commercially available in the time period analyzed. For stationary sources, these included suppression of NO_x formation and removal of NO_x from stack gas. Suppression of NO_x formation is most effective with large combustion sources. Suppression mechanisms include alteration of operating conditions by modifying the fuel or air supply, by lowering combustion intensity or temperature, or by combining these techniques. Removal of NO_x from combustion stack gases can be accomplished by ammonia injection, which reduces NO_x to elemental nitrogen. Removal of NO_x from stack gases is most effective with noncombustion sources, chiefly chemical manufacturing industries. Removal techniques include catalytic reduction with wet chemical scrubbing extended and chilled absorption, and molecular sieve adsorption. (See Appendix C for more information on stationary source controls.)

NO_x control measures used for mobile sources include an exhaust gas recirculation (EGR) valve and associated equipment, an open-loop oxidation catalyst system, and a three-way plus closed-loop oxidation catalyst system, for analyses of 2.0, 1.5, and 1.0 gram per mile FMVCP emission standards, respectively.

It should be recognized that NO_x control programs developed in this report, and the cost analyses upon which it is based, are hypothetical. Actual control programs are developed by State and local air quality management agencies in the state implementation planning process. Actual national costs of NO_x control programs will be the sum of many individual state decisions, and of course may differ from those developed for this regulatory impact analysis. In addition, this analysis does not "force" attainment of any of the alternative NAAQS investigated. As mentioned, the hypothetical national control program only uses reasonably available control measures. If an area cannot attain an analyzed alternative NAAQS using these measures, the fact is so noted. No attempt is made to develop a more stringent program using NO_x control techniques under development or being proposed. Cost and efficiency data do not exist for these new techniques in sufficient detail to incorporate them in the least-cost program used to calculate national NO_x control costs. Finally, in this national-level analysis, it is frequently necessary to use national averages for important factors such as emissions growth rate.

B. NATIONAL CONTROL COSTS

National NO_x control costs are presented for the current 0.053 ppm annual average and for two alternatives: 0.06 and 0.07 ppm. The cost estimates for reducing nitrogen oxides emissions to meet, or approach as closely as possible, each alternative NAAQS standard by 1985 or 1990 are presented below. A number of estimates are provided in order to cover alternative motor vehicle emission standards currently being discussed by Congress, and to account for whether or not NO_x inspection and maintenance programs will be installed in major urbanized areas.

Two methodologies are used in the analysis (EPA, 1982c) for estimating nationwide control costs. They are based on current knowledge of NO_2 formation, especially in situations likely to cause high observed NO_2 concentrations. The situations modeled reflect different types of NO_2 episodes. One uses linear roll-back and includes only emissions from mobile and stationary area sources in the emission inventory. This approach accounts for suppressed mixing episodes where an inversion limits vertical mixing and where point sources with stack heights above the inversion layer do not affect ground-level concentrations. Ambient concentrations of NO_2 during these episodes are likely to be recorded by the existing network of NO_2 monitors. The second methodology accounts for situations where emissions from point sources can cause high NO_2 levels at the point where the plume hits the ground. Ground-level NO_2 concentrations for each significant source in the National Emissions Data System (NEDS) point source file of NO_x emitters are estimated with a dispersion model, considering source interaction within plants. A modified ozone-limiting approach is used to translate NO_x into NO_2 (Cole and Summerhays, 1979).

In either case, the observed or calculated NO_2 annual average value is compared with the alternative NAAQS under investigation to determine how much reduction in NO_x emissions is required to attain the NAAQS and an integer linear program is used to determine the most cost effective control stategy.

The least-cost set of control strategies is selected using estimated annualized costs to industries or to owners of area and mobile NO_x sources. However, costs presented in EPA (1982c) and in this report are social costs, or close proxies of them representing aggregrate before-tax costs. EPA (1982c) presents in detail how the two cost indices are related. Appendix B of this report describes how the control costs in EPA (1982c) were updated using more recent NO_x data, new mobile source emissions estimates, and 1984 dollars.

There are other NO_x control costs incurred by industry and the public that do not vary with choice of a NO_2 ambient standard. These costs are incurred to meet (1) the Federal Motor Vehicle Control Program (FMVCP) for automobile and truck NO_x controls, as governed by Title II of the Clean Air Act, and (2) new source performance standards (NSPS) for certain new large point sources of NO_x emissions, as governed by section 111 of the Act. The major categories of point, or stationary, sources affected by a NO_x NSPS are: utility boilers, coal-fired and oil- or gas-fired, industrial boilers, stationary gas turbines, reciprocating internal-combustion engines, and nitric acid plants.

For the sake of completeness, both EPA (1982c) and this report present FMVCP and NSPS control costs even though they are not affected by level of the NO_2 standard. As will be seen, these costs--particularly FMVCP costs--are much higher than the incremental cost incurred to just attain alternative ambient NO_2 standards. Appendix B revises and adds to the FMVCP costs in EPA (1982c).

Estimates of national NO_x control costs appear in Tables 5.1-5.6. Tables 5.1-5.3 are for 1985 annualized cost estimates, for the 1, 1.5, and 2 gpm FMVCP alternatives respectively. Tables 5.4-5.6 depict 1990 annualized costs for the same FMVCP alternatives. The estimates are in constant March 1984 dollars rounded to the nearest ten million dollars. Finally, all point source cost estimates are based on using a 0.01 ppm NO_2 background value in the point source modeling analysis. EPA (1982c) includes results using a zero NO_2 background value. If such a value is used, there would be no point source costs in the Tables shown in this report, but all other costs remain the same.

Also depicted in the Tables are the number of non-attainment urban areas remaining after all reasonably available control measures have been applied. As described in Appendix B, all areas in the country can attain the current 0.053 ppm standard (and all higher alternatives) in both 1985 and 1990, except for one area where the 0.053 ppm value cannot be attained in 1985 without instituting a NO_x I&M program.

As can be readily seen, the vast majority of NO_x control costs are due to the FMVCP and NSPS programs, which are not directly tied to the ambient NO_2 standard. The incremental costs associated with various air standards, then, are those attributed to I&M, TCM, and stationary and area source programs, which might be needed in addition to FMVCP and NSPS controls. While the incremental costs of going from one standard to another can be determined simply by subtracting total NO_x control costs for any consistent set of I&M and FMVCP conditions, the result is difficult to interpret since the non-attainment situation differs for the various

Table 5.1

NATIONAL ANNUALIZED 1985 RACT/RACM CONTROL COSTS[1] FOR THREE ALTERNATIVE NO_2 NAAQS, ASSUMING A 1 GPM FMVCP[2]

($$10^6$)[a]

Alternative Annual Average NO_2 NAAQS
ppm

Control Strategies	0.053		0.060		0.070	
	With I&M	No I&M	With I&M	No I&M	With I&M	No I&M
FMVCP	1,910	1,910	1,910	1,910	1,910	1,910
Additional Mobile/Area	120	180	0	0	0	0
Point Sources[b]	10	10	–[d]	–[d]	0	0
NSPS[c]	110	110	110	110	110	110
Total NO_x Control Costs	2,150	2,210	2,020	2,020	2,020	2,020
Number of Remaining Non-Attainment Areas	0	1	0	0	0	0

Abbreviations:
RACT: Reasonably Available Control Technology
RACM: Reasonably Available Control Measures
NO_2 : Nitrogen Dioxide
NAAQS: National Ambient Air Quality Standard
GPM : Gram per mile
FMVCP: Federal Motor Vehicle Control Program
PPM : Parts per million
I&M : Inspection and Maintenance Program

Notes: [a] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

[b] The point source figures are those obtained from using a NO_2 background value of 0.01 ppm in the modeling analysis. A 0.0 ppm value was also used; point source costs are zero in all cases if a zero background NO_2 level is assumed.

[c] A range of costs are presented in EPA (1982) for this item but have been reduced to the mid-value for purposes of this presentation.

[d] Less than $5 × 10^6, which is rounded to zero.

Source: U.S. EPA, 1982c. Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT). Research Triangle Park, N.C., and Appendix B.

Table 5.2

NATIONAL ANNUALIZED 1985 RACT/RACM CONTROL COSTS[1] FOR THREE ALTERNATIVE NO_2 NAAQS, ASSUMING A 1.5 GPM FMVCP

($\$10^6$)[a]

	Alternative Annual Average NO_2 NAAQS ppm					
	0.053		0.060		0.070	
Control Strategies	With I&M	No I&M	With I&M	No I&M	With I&M	No I&M
FMVCP	1,640	1,640	1,640	1,640	1,640	1,640
Additional Mobile/Area	140	180	30	30	0	0
Point Sources[b]	10	10	–[d]	–[d]	0	0
NSPS[c]	110	110	110	110	110	110
Total NO_x Control Costs	1,900	1,940	1,780	1,780	1,750	1,750
Number of Remaining Non-Attainment Areas	0	1	0	0	0	0

Abbreviations:

RACT:	Reasonably Available Control Technology
RACM:	Reasonably Available Control Measures
NO_2 :	Nitrogen Dioxide
NAAQS:	National Ambient Air Quality Standard
GPM :	Gram per mile
FMVCP:	Federal Motor Vehicle Control Program
PPM :	Parts per million
I&M :	Inspection and Maintenance Program

Notes: [a] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

[b] The point source figures are those obtained from using a NO_2 background value of 0.01 ppm in the modeling analysis. A 0.0 ppm value was also used; point source costs are zero in all cases if a zero background NO_2 level is assumed.

[c] A range of costs are presented in EPA (1982) for this item but have been reduced to the mid-value for purposes of this presentation.

[d] Less than \$5 x 10^6, which is rounded to zero.

Source: U.S. EPA, 1982c. Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT). Research Triangle Park, N.C., and Appendix B.

Table 5.3

NATIONAL ANNUALIZED 1985 RACT/RACM CONTROL COSTS[1] FOR THREE ALTERNATIVE NO_2 NAAQS, ASSUMING A 2 GPM FMVCP[2]

($\$10^6$)[a]

Control Strategies	Alternative Annual Average NO_2 NAAQS ppm 0.053 With I&M	 0.053 No I&M	 0.060 With I&M	 0.060 No I&M	 0.070 With I&M	 0.070 No I&M
FMVCP	1,610	1,610	1,610	1,610	1,610	1,610
Additional Mobile/Area	140	180	30	30	0	0
Point Sources[b]	10	10	-[d]	-[d]	0	0
NSPS[c]	110	110	110	110	110	110
Total NO_x Control Costs	1,870	1,910	1,750	1,750	1,720	1,720
Number of Remaining Non-Attainment Areas	0	1	0	0	0	0

Abbreviations:

RACT:	Reasonably Available Control Technology
RACM:	Reasonably Available Control Measures
NO_2 :	Nitrogen Dioxide
NAAQS:	National Ambient Air Quality Standard
GPM :	Gram per mile
FMVCP:	Federal Motor Vehicle Control Program
PPM :	Parts per million
I&M :	Inspection and Maintenance Program

Notes: [a] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

[b] The point source figures are those obtained from using a NO_2 background value of 0.01 ppm in the modeling analysis. A 0.0 ppm value was also used; point source costs are zero in all cases if a zero background NO_2 level is assumed.

[c] A range of costs are presented in EPA (1982) for this item but have been reduced to the mid-value for purposes of this presentation.

[d] Less than $\$5 \times 10^6$, which is rounded to zero.

Source: U.S. EPA, 1982c. Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT). Research Triangle Park, N.C., and Appendix B.

Table 5.4

NATIONAL ANNUALIZED 1990 RACT/RACM CONTROL COSTS[1] FOR THREE ALTERNATIVE NO_2 NAAQS, ASSUMING A 1 GPM FMVCP[2]

($\$10^6$)[a]

Control Strategies	Alternative Annual Average NO_2 NAAQS ppm					
	0.053		0.060		0.070	
	With I&M	No I&M	With I&M	No I&M	With I&M	No I&M
FMVCP	4,470	4,470	4,470	4,470	4,470	4,470
Additional Mobile/Area	0	0	0	0	0	0
Point Sources[b]	–[d]	–[d]	–[d]	–[d]	0	0
NSPS[c]	250	250	250	250	250	250
Total NO_x Control Costs	4,720	4,720	4,720	4,720	4,720	4,720
Number of Remaining Non-Attainment Areas	0	0	0	0	0	0

Abbreviations:		
	RACT:	Reasonably Available Control Technology
	RACM:	Reasonably Available Control Measures
	NO_2 :	Nitrogen Dioxide
	NAAQS:	National Ambient Air Quality Standard
	GPM :	Gram per mile
	FMVCP:	Federal Motor Vehicle Control Program
	PPM :	Parts per million
	I&M :	Inspection and Maintenance Program

Notes: [a] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

[b] The point source figures are those obtained from using a NO_2 background value of 0.01 ppm in the modeling analysis. A 0.0 ppm value was also used; point source costs are zero in all cases if a zero background NO_2 level is assumed.

[c] A range of costs are presented in EPA (1982) for this item but have been reduced to the mid-value for purposes of this presentation.

[d] Less than $\$5 \times 10^6$, which is rounded to zero.

Source: U.S. EPA, 1982c. Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT). Research Triangle Park, N.C., and Appendix B.

Table 5.5

NATIONAL ANNUALIZED 1990 RACT/RACM CONTROL COSTS[1] FOR THREE ALTERNATIVE NO_2 NAAQS, ASSUMING A 1.5 GPM FMVCP

($\$10^6$)[a]

Control Strategies	Alternative Annual Average NO_2 NAAQS ppm					
	0.053		0.060		0.070	
	With I&M	No I&M	With I&M	No I&M	With I&M	No I&M
FMVCP	2,850	2,850	2,850	2,850	2,850	2,850
Additional Mobile/Area	0	0	0	0	0	0
Point Sources[b]	–[d]	–[d]	–[d]	–[d]	0	0
NSPS[c]	250	250	250	250	250	250
Total NO_x Control Costs	3,100	3,100	3,100	3,100	3,100	3,100
Number of Remaining Non-Attainment Areas	0	0	0	0	0	0

Abbreviations:		
	RACT:	Reasonably Available Control Technology
	RACM:	Reasonably Available Control Measures
	NO_2 :	Nitrogen Dioxide
	NAAQS:	National Ambient Air Quality Standard
	GPM :	Gram per mile
	FMVCP:	Federal Motor Vehicle Control Program
	PPM :	Parts per million
	I&M :	Inspection and Maintenance Program

Notes: [a] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

[b] The point source figures are those obtained from using a NO_2 background value of 0.01 ppm in the modeling analysis. A 0.0 ppm value was also used; point source costs are zero in all cases if a zero background NO_2 level is assumed.

[c] A range of costs are presented in EPA (1982) for this item but have been reduced to the mid-value for purposes of this presentation.

[d] Less than $\$5 \times 10^6$, which is rounded to zero.

Source: U.S. EPA, 1982c. Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT). Research Triangle Park, N.C., and Appendix B.

Table 5.6

NATIONAL ANNUALIZED 1990 RACT/RACM CONTROL COSTS[1] FOR THREE ALTERNATIVE NO_2 NAAQS, ASSUMING A 2 GPM FMVCP[2]

($\$10^6$)[a]

Control Strategies	0.053 With I&M	0.053 No I&M	0.060 With I&M	0.060 No I&M	0.070 With I&M	0.070 No I&M
	Alternative Annual Average NO_2 NAAQS ppm					
FMVCP	2,640	2,640	2,640	2,640	2,640	2,640
Additional Mobile/Area	10	100	0	0	0	0
Point Sources[b]	-[d]	-[d]	-[d]	-[d]	-[d]	-[d]
NSPS[c]	250	250	250	250	250	250
Total NO_x Control Costs	2,900	2,990	2,890	2,890	2,890	2,890
Number of Remaining Non-Attainment Areas	0	0	0	0	0	0

Abbreviations:
RACT: Reasonably Available Control Technology
RACM: Reasonably Available Control Measures
NO_2 : Nitrogen Dioxide
NAAQS: National Ambient Air Quality Standard
GPM : Gram per mile
FMVCP: Federal Motor Vehicle Control Program
PPM : Parts per million
I&M : Inspection and Maintenance Program

Notes: [a] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

[b] The point source figures are those obtained from using a NO_2 background value of 0.01 ppm in the modeling analysis. A 0.0 ppm value was also used; point source costs are zero in all cases if a zero background NO_2 level is assumed.

[c] A range of costs are presented in EPA (1982) for this item but have been reduced to the mid-value for purposes of this presentation.

[d] Less than $\$5 \times 10^6$, which is rounded to zero.

Source: U.S. EPA, 1982c. Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (DRAFT). Research Triangle Park, N.C., and Appendix B.

cases. Thus, there is no consistent basis for comparison. The incremental control costs for 1985 and 1990 along with the number of remaining non-attainment areas, are presented in Tables 5.7 and 5.8.

The present value (PV) of future expenditures made by individuals and business to control NOx emissions can be approximated by applying the PV formula to the cost estimates provided in Tables 5.1 to 5.6. The formula is:

$$PV = C\ (1 + r)^{-t}$$

where: PV = present value of a future expenditure
C = cost of the future expenditure
r = annual interest rate
t = elapsed time in years

For our purposes, r=10% and t=1 for 1985 and t=6 for 1990. The resultant discount factors therefore are: 0.909 for 1985 and 0.565 for 1990. Applying these factors to the cost estimates provided for 1985 and 1990 results in the following present value cost estimates in millions of dollars for the "with I&M" case.

	Alternative NAAQS Standards (ppm)		
	0.053	0.060	0.070
1 gpm FMVCP			
1985	1,950	1,840	1,840
1990	2,670	2,670	2,670
1.5 gpm FMVCP			
1985	1,730	1,620	1,590
1990	1,750	1,750	1,750
2.0 gpm FMVCP			
1985	1,700	1,590	1,560
1990	1,640	1,630	1,630

Again, most of these present value expenditures are due to FMVCP and NSPS costs that are not affected by a national ambient air quality standard.

C. TRANSACTIONAL COSTS (SECONDARY COSTS)

According to Office of Management and Budget guidance on performing regulatory impact analyses, a complete cost analysis of major governmental actions should contain an evaluation of certain secondary costs associated with that action. These include governmental regulatory costs, adjustment costs for unemployed resources, and costs associated with adverse effects on market structure, innovation, and productivity. Most of these items were only cursorily investigated in the cost and economic assessment (EPA, 1982c) underlying this RIA. Consequently, they are only discussed qualitatively below.

1. Governmental Regulatory Costs

Both federal and state agencies are involved in establishing, implementing and enforcing the national ambient air quality standards. EPA provides scientific and technical analyses in developing, reviewing, and setting air standards. It also provides technical support in developing and maintaining computerized national data systems that store ambient air quality and emissions data. In addition, EPA provides technical guidance to the states in operating and reporting ambient monitoring networks, developing state implementation plans (SIPs), and undertaking enforcement actions against certain violators of the state's own rules and regulations.

It is extremely difficult to separate out that part of the total costs for these functions attributable to NO_2, since it is only one of six NAAQS and numerous other pollutants that are more or less

Table 5.7

INCREMENTAL 1985 ANNUALIZED CONTROL COSTS[1] ASSOCIATED WITH CHANGING FROM ONE NO_2 ANNUAL NAAQS TO ANOTHER

(March 1984 $\$10^6$)

	FMVCP Standard (gpm) 1.0		1.5		2.0	
Standard Change (ppm) Going From To	Additional Costs ($)	Additional Remaining Non-Attainment Areas	Additional Costs ($)	Additional Remaining Non-Attainment Areas	Additional Costs ($)	Additional Remaining Non-Attainment Areas
	-- No I & M --					
0.070 → 0.060	0	0	30	0	30	0
0.060 → 0.053	190	1	160	1	160	1
	-- With I & M --					
0.070 → 0.060	0	0	30	0	30	0
0.060 → 0.053	130	0	120	0	120	1

Abbreviations:

NO_2 :	Nitrogen Dioxide
NAAQS:	National Ambient Air Quality Standard
GPM :	Gram per mile
FMVCP:	Federal Motor Vehicle Control Program
PPM :	Parts per million
I&M :	Inspection and Maintenance Program

Footnote: [1] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

Source: Tables 1, 2, and 3.

Table 5.8
INCREMENTAL 1990 ANNUALIZED CONTROL COSTS[1] ASSOCIATED WITH CHANGING FROM ONE NO_2 ANNUAL NAAQS TO ANOTHER

(March 1984 $\$10^6$)

	FMVCP Standard (gpm)					
	1.0		1.5		2.0	
Standard Change (ppm) Going From To	Additional Costs ($)	Additional Remaining Non-Attainment Areas	Additional Costs ($)	Additional Remaining Non-Attainment Areas	Additional Costs ($)	Additional Remaining Non-Attainment Areas
-- No I & M --						
0.070 → 0.060	0	0	0	0	0	0
0.060 → 0.053	0	0	0	0	100	0
-- With I & M --						
0.070 → 0.060	0	0	0	0	0	0
0.060 → 0.053	0	0	0	0	10	0

Abbreviations:
NO_2 : Nitrogen Dioxide
NAAQS: National Ambient Air Quality Standard
GPM : Gram per mile
FMVCP: Federal Motor Vehicle Control Program
PPM : Parts per million
I&M : Inspection and Maintenance Program

Footnote: [1] All costs are rounded to the nearest ten million dollars. The estimates are in constant March 1984 dollars.

Source: Tables 4, 5, and 6.

handled simultaneously by EPA in performing the functions noted above. However, EPA's costs to review the NO_2 NAAQS and promulgate a revised standard can be estimated. The items covered to date include: (1) scientific review of health literature and development of the NO_2 Criteria Document and Staff Paper, (2) review of existing ambient data to determine potential problem areas, (3) development of a set of control strategies, which are then costed out, (4) analysis of the economic impacts associated with these costs, (5) analysis of exposures to alternative NO_2 standards, (6) development of the regulatory package for proposal, and (7) internal review of the various regulatory documents. EPA's estimated total costs for NO_2 for these items are:

1. 16 person years of staff time.
2. $1.5 million of contract funds.
3. $120,000 of computer time.

This comes to a total of approximately $2.5 million (in 1984 dollars). It is a one-time cost* that occurs over 3 fiscal years. This estimate does not include any costs of maintaining NO_2 air quality or emissions inventory data. It also does not include any guidance activities costs. The problem of costing these activities is difficult as data do not exist to exactly apportion total costs of these activities to NO_2. However, they are estimated to be an order-of-magnitude lower than the cost incurred to review and set the standard.

States, and, if they so delegate, local governments, actually implement Clean Air Act provisions directed toward attaining and maintaining NAAQS.

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*Since section 109 of the Clean Air Act requires that all NAAQS be reviewed every five years, it will be a repetitive one-time cost.

Their major implementing functions include operating air monitors and reporting ambient air quality data (required under sections 110 and 317 of the Act), developing SIPs (required under section 110), and enforcing these plans. For the most part, these are labor-intensive activities. The Economic Impact Assessment of the lead NAAQS (EPA, 1978b) provides data that can be used to estimate roughly the costs to state and local governments in implementing the promulgated NO_2 NAAQS. That report suggests that these annual costs would be on the order of 50 person-years of effort plus $1.5 million in monitoring equipment and other capital costs.[1] State/local control costs, then, would be around $6.8 million (in 1984 dollars) annually.

Total annual governmental NO_2 control costs are derived simply by adding the annualized one-time standard-setting costs with other miscellaneous federal costs (assumed to be $0.5 million) and adding this to the $6.8 million state/local estimate. Total annual costs obtained in this manner for a five-year review cycle are approximately $7.8 million.

2. Adjustment Costs for Unemployed Resources

Three types of costs occur if a regulatory action results in unemployment of labor or underuse of other productive resources. These are: loss of value in the resources required to produce lost output, resource reallocation costs (such as moving costs), and unemployment transfer payments.

EPA does not believe any significant unemployment impacts are associated with the NO_2 NAAQS being reviewed (see EPA, 1982c). In only one major industrial sector does the estimated initial investment cost for NO_2 control equipment exceed one percent of the usual annual capital budget of the industrial sector. Capital costs in that sector, extraction of natural gas, amount to slightly less than 1.5% of annual capital outlays. The effects on capital availability, product price, and import substitution are also minor. In addition, no plant closings are predicted due to the installation of NO_2 controls to meet any of the annual average NO_2 NAAQS investigated.

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[1] These estimates apply to on-going activities and not to one-time events associated with just implementing a new NAAQS.

3. Adverse Effects on Market Structure

As just mentioned, none of the proposed NO_2 NAAQS has a significant impact on product price, capital availability, or import substitution. Likewise, their impacts on corporate debt and debt/equity ratios are small. At most, a NO_2 NAAQS will add 0.020 percent to the cost of producing goods. Also, in the U.S. census region containing an urban area where NO_2 controls are theoretically needed to attain the 0.053 NAAQS, industrial area source control costs represent less than 0.5 percent of value added by the manufacturing sector.

Lacking a distribution of vehicle ownership, it is not possible to estimate accurately the impact of I&M costs on the commercial and industrial sectors. However, the average per vehicle cost of I&M for a failed vehicle - approximately $23 - is not considered a significant increment in the annual cost of vehicle operation for either the commercial or industrial sectors. Compared to receipts for the commercial and industrial sectors, the entire cost for I&M does not constitute even 0.1 percent of sales plus value added in the area where costs are incurred. Thus, there will probably be little or no impact on market structure in the industrial sectors affected by NO_x emission controls needed to attain alternative NO_2 NAAQS.

VI. EVALUATING BENEFITS AND COSTS

A. INTRODUCTION

Since it was felt that a credible attempt could not be made to estimate the benefits of various NO_2 ambient standards within project constraints, and therefore a quantitative benefit-cost assessment could not be done, analyses of the incremental costs to reduce potentially adverse concentrations of NO_2 (hereafter referred to as ICAs) were performed instead. These analyses concentrated on two of the alternative annual standards studied in the preceding national cost analysis, namely 0.053 ppm and 0.060 ppm. The object of the ICAs was to determine the incremental control costs and the incremental NO_2 concentrations resulting from more stringent NO_2 standards. In so doing, estimates could be obtained of the incremental costs per concentration reduction between standards.[1]

While this information does not reveal which standard would be best in an economic sense--only the cost, and not the "benefit", of reducing adverse levels of NO_2 has been estimated--it does provide a partial measure of the relative impacts of the alternative NO_2 standards.

B. Framework and Scope of the Incremental Cost Analysis

This section discusses the procedures, assumptions, and scenarios that were used in the ICAs.

1. Cost Analysis Procedures and Assumptions

The NO_2 control cost estimates were derived by analyzing only the requirements each standard imposed on area and mobile sources since major stationary point sources were not considered a significant contributor to monitored ambient air quality (See Chapter V).

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[1] The original RIA used reduced people exposures as a measure of effect in the ICA. This ICA could not use this preferred effects measure because of time and budget constraints.

Baseline NO_2 concentrations were calculated assuming that several different NO_2 Federal Motor Vehicle Control Program (FMVCP) standards were in effect. In areas where baseline concentrations exceeded the standard, additional controls were applied in order of relative cost effectiveness to bring the areas into compliance. The controls considered included area source controls on commercial boilers and small industrial boilers, automobile inspection and maintenance (I&M) programs, and transportation control measures (TCM). Residential heating, though more cost effective than some of these controls, was only applied as a last resort to achieve attainment.

2. Concentration of NO_2 as Effects Measure--Procedures and Assumptions

Given time and budget constraints, the only effects measure available for use in the ICA was the design value level of forecast air quality--the annual average NO_2 concentration in PPM--used in the cost analysis under baseline and alternative regulations. The incremental change in the average annual concentration of NO_2 was thus used as the measure of effect when moving from a less to more stringent regulatory alternative.

3. Cases Analyzed

The ICA was limited to one urban area for six scenarios regarding different combinations of FMVCP and the year of implementation and compliance. Only Los Angeles was projected to need controls beyond FMVCP and NSPS to meet ambient NO_2 standards as stringent as 0.060 ppm on an annual basis. Analyses were conducted assuming three different levels of FMVCP--1.0, 1.5 and 2.0 grams per mile (gpm). And finally, analyses were performed assuming 1985 and 1990 as alternative dates of implementation and compliance for the NO_2 NAAQS.

C. Incremental Cost Analysis

This section shows the estimates of costs per 0.001 ppm change in annual NO_2 concentrations associated with incremental changes in the NO_2 ambient standard. Tables 6.1 and 6.2 show the costs and ambient concentrations associated with alternative NO_2 standards. These tables were used to construct the incremental costs per 0.001 ppm change in annual NO_2 concentrations for moving from less to more stringent NO_2 standards.

Several noteworthy conclusions can be drawn from observing Tables 6.1 and 6.2. First of all, delay of the implementation/compliance date for either the 0.060 or 0.053 ppm standard can significantly reduce the cost of either alternative. For instance, under the 2.0 gpm FMVCP scenario, the cost of the 0.053 ppm standard under a 1985 implementation date is 140 million dollars. If the compliance date is extended to 1990, the annualized cost drops to 10 million dollars. This decline can be explained by the general decline in ambient NO_2 levels over time. More specifically, ambient NO_2 concentrations are falling as the old stock of automobiles are replaced by new models with NO_2 controls. A second conclusion that can be drawn from Tables 6.1 and 6.2 is that more stringent FMVCPs will reduce the costs of controls associated with alternative NO_2 standards. In some cases, more stringent FMVCPs will cause the ambient standards to be attained without any additional controls above FMVCP being required. Thirdly, the tables show that in the 1985 attainment case, the cost of the 0.053 standard is considerably larger than the 0.060 standard. This observation is explained by the fact that the baseline air quality estimate in Los Angeles is already near 0.060 ppm.

Table 6.1

ANNUALIZED COSTS INCURRED UNDER ALTERNATIVE NO_2 NAAQS[1]

(Millions of March 1984 Dollars)

1985

	Alternative NO_2 NAAQS		
FMVCP Standard	Baseline	0.060 ppm	0.053 ppm
1.0 gpm	0	0	120
1.5 gpm	0	30	140
2.0 gpm	0	30	140

1990

	Alternative NO_2 NAAQS		
FMVCP Standard	Baseline	0.060 ppm	0.053 ppm
1.0 gpm	0	0	0
1.5 gpm	0	0	0
2.0 gpm	0	0	+10

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[1] Costs above and beyond those incurred by NSPS and FMVCP.

Table 6.2

NO_2 CONCENTRATIONS ACHIEVED UNDER ALTERNATIVE NO_2 NAAQS[1]
(ANNUAL AVERAGES)

1985

FMVCP Standard	Alternative NO_2 NAAQS Baseline	 0.060 ppm	 0.053 ppm
1.0 gpm	0.060	0.060	0.053
1.5 gpm	0.061	0.055	0.053
2.0 gpm	0.061	0.055	0.053

1990

FMVCP Standard	Alternative NO_2 NAAQS Baseline	 0.060 ppm	 0.053 ppm
1.0 gpm	0.052	0.052	0.052
1.5 gpm	0.053	0.053	0.053
2.0 gpm	0.057	0.057	0.052

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[1] In some cases, the discrete characteristics of additional controls cause the ambient NO_2 forecast to overshoot the actual ambient standard.

Table 6.3 shows the results of the ICA analysis. The numbers show the change in cost per change in 0.001 ppm annual average of NO_2. Changes in 0.001 ppm were selected as opposed to one ppm changes because none of the alternatives change the ambient NO_2 by more than a few one-thousandths of a ppm. The table shows again that the incremental costs of moving to more stringent standards are higher for 1985 than for 1990 compliance. For example, the incremental cost of moving from the 0.060 to the 0.053 ppm standard with an FMVCP of 1.0 gpm is 17.1 million dollars per 0.001 ppm reduction in 1985 and zero in 1990. A second finding observable from Table 6.3 is that in 1985, the incremental cost of the 0.053 ppm standard is higher than the incremental cost of the 0.060 ppm standard. This occurs because baseline air quality is already close to 0.060 ppm and hence less costs are needed to improve air quality to the less stringent levels. By 1995, there is less difference in the incremental costs between the two standards since no additional costs are needed to meet even the 0.053 ppm standard except under the 2.0 gpm FMVCP.

D. QUALIFICATIONS

1. Use of ICA in General

ICA, in general, embodies the same methodology as cost effectiveness analysis (CEA). The usefulness of such tools can allow one to identify the least cost way to achieve a given goal. In addition, the methods can eliminate inefficient ways of achieving given goals. The techniques used above can in no way help identify the optimal goal in an economic efficiency sense. Hence, the ICA can only be used to identify the opportunity costs of implementing more stringent standards and cannot identify the socially desired NO_2 NAAQS from an economic point of view.

Table 6.3

INCREMENTAL COSTS PER PPM NO_2 CONCENTRATION REDUCTION[1]

(Millions of 1984 Dollars Per 0.001 ppm Reduction)

1985

	Change in NO_2 NAAQS	
FMVCP Standard	Baseline to 0.060 ppm	0.060 to 0.053 ppm
1.0 gpm	---	17.1
1.5 gpm	5.0	55.0
2.0 gpm	5.0	55.0

1990

	Change in NO_2 NAAQS	
FMVCP Standard	Baseline to 0.060 ppm	0.060 to 0.053 ppm
1.0 gpm	---	---
1.5 gpm	---	---
2.0 gpm	---	2.0

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[1] Annual average changes in NO_2 concentrations.

2. The Effects Measure of the ICA

ICA--and for that matter CEA--can use a number of effects measures in ascertaining the cost effectiveness of alternative actions. Since the general purpose of the NAAQS is to reduce adverse effects of pollution on sensitive populations, one measure of effectiveness for ICA could have been the reduction in disease incidence. Insufficient scientific information was available to use this effectiveness measure however. In fact, had the information been available, a partial (other benefits not measured) benefit and benefit cost analysis would have been performed in lieu of the ICA. Two other measures of effects that could have been used include reduced exposures above adverse concentration levels and/or reduced emissions of NO_2. The latter was not chosen because the ultimate goal of the NAAQS decision-making process is to reduce pollution levels below those considered harmful to public health and welfare and not to reduce emissions per se. The former method--reductions in exposures--was originally used in the ICA. However, updates in the cost data's benchmark air quality levels caused inconsistencies between the old exposure analysis and the most recent cost analysis. Due to limitations in time and budget the exposure analysis was not updated.

3. Limitations in the Effects Measure of the ICA

To recapitulate, the effects measures used in the ICA are the 0.001 ppm reductions in ambient air quality of enforcing more stringent NO_2 NAAQS. This measure of ambient air quality is the same as used in the cost analysis. The cost analysis used the design value (Chapter V) as a measure of ambient air quality for urban areas to examine compliance with alternative NAAQS and to determine appropriate control measures to ensure compliance.

This measure may not fully represent the ambient air quality levels and changes across alternative standards for regions as large as the urban areas analyzed. Hence, the ICA results should be interpreted with caution.

VII. SUMMARY OF THE RATIONALE FOR SELECTING THE PROPOSED STANDARDS

This Chapter summarizes the Agency's rationale for retention of the current annual NO_2 primary and secondary NAAQS. A more complete discussion of the rationale is contained in the proposal preamble.

A. HEALTH EFFECTS AND THE PRIMARY STANDARD

The current primary NAAQS for NO_2 is 0.053 ppm (100 $\mu g/m^3$), averaged over 1 year. In addition to requiring review of the existing criteria and standards for NO_2, in 1977 Congress amended section 109(c) of the Clean Air Act to require the Administrator to promulgate a short-term NO_2 primary standard with an averaging time of not more than 3 hours unless he or she finds no significant evidence that such a standard is required to protect public health (Section 109(c)).

Section 109(b)(1) of the Clean Air Act requires EPA to set primary standards, based on air quality criteria and allowing an adequate margin of safety, which in the Administrator's judgment are requisite to protect the public health. The legislative history of the Act makes quite clear the Congressional intent to protect sensitive persons who in the normal course of daily activity are exposed to the ambient environment. Air quality standards are to be established with reference to protecting the health of a representative, statistically related, sample of persons comprising the sensitive group rather than a single person in such a group.

EPA's objective, in reviewing the adequacy of the existing annual NO_2 primary standard and the need for a separate short-term primary standard, therefore, is to set primary air quality standards which accurately reflect consideration of the existing scientific evidence, an adequate assessment of the uncertainties of this evidence, and a reasonable provision for scientific and medical knowledge yet to be acquired, so as to protect sensitive population groups with an adequate margin of safety. The Criteria Document (EPA, 1983) supports the conclusion that a clear threshold of adverse health effects cannot be identified with certainty for NO_2. There is rather a continuum consisting of NO_2 levels at which health effects are certain through levels at which scientists can generally agree that health effects have been convincingly shown, and down to levels at which the indications of health effects are less certain and harder to identify. (This does not necessarily mean that there is no threshold, other than zero, for NO_2; it simply means no clear threshold can be identified with certainty based on existing medical evidence.) Thus, selecting a standard that takes into account the known continuum of effects is a judgment of prudent health policy, and does not imply some discrete or exact margin of safety appended to a known threshold.

Determinations Concerning the Averaging Time and Standard Level

As discussed previously, EPA is required both to review the adequacy of the existing 0.053 ppm annual NO_2 standard and to determine whether a short-term (less than 3 hours) NO_2 standard is required to protect public health. Although the scientific literature supports the conclusion that NO_2 does pose a risk to human health, there is no single study or group of studies that clearly defines human exposure-response relationships at or near current ambient NO_2 levels. This situation exists because of both methodological limitations of health effects research and lack of sufficient studies involving population groups suspected of being particularly sensitive to NO_2. Based on the review of the health effects evidence presented in the Criteria Document, however, both EPA and the CASAC have concluded that studies have demonstrated the occurrence of health effects resulting from both short-term and long-term NO_2 exposures. Unfortunately, the various uncertainties in the health effects data make it impossible to specify at this time the lowest level at which adverse health effects are believed to occur in humans due to either short- or long-term NO_2 exposures.

Annual Standard. In reviewing the scientific basis for an annual standard, EPA finds that the evidence suggesting the most serious health effects associated with NO_2 exposures (e.g., emphysematous alterations in the lung and increased susceptibility to infection) comes from animal studies conducted at concentrations well above those permitted in the ambient air by the current annual standard. The major limitation of these studies for standard-setting purposes is that currently there is no satisfactory method for quantitatively extrapolating exposure-response results from these animal studies directly to humans. However, the seriousness of these effects coupled with the biological similarities between humans and test animals suggests that there is some risk to human health from long-term exposure to elevated NO_2 levels.

Other evidence suggesting health effects related to long-term, low-level exposures, such as the community epidemiology and gas stove community studies, provides some qualitative support for concluding that there may be a relationship between long-term human exposure to near-ambient levels of NO_2 and adverse health effects. However, various limitations in these studies (e.g., unreliable or insufficient monitoring data and inadequate treatment of potential confounding factors such as humidity and pollutants other than NO_2) preclude derivation of quantitative dose-response relationships.

Given the uncertainty associated with the extrapolation from animal to man, the seriousness of the observed effects, and the inability to determine from the available data an effects level for humans, EPA believes it would be prudent public health policy to maintain the current annual standard of 0.053 ppm. As discussed in the proposal notice, EPA is also concerned that any relaxation of the current annual standard would allow a rise in the frequency and severity of short-term ambient NO_2 concentrations. The results of EPA's analysis of short-term ambient concentrations in areas that meet the current 0.053 ppm annual standard and alternative annual standards in the range 0.05 to 0.08 ppm are discussed in more detail in McCurdy and Atherton (1983) and in the proposal preamble (49 FR 6873). Despite the lack of a firm relationship between various averaging times, it was observed that where the annual average is at or below the current 0.053 ppm standard, days with one-hour concentrations in excess of any specified level (including levels in the range 0.15 to 0.30 ppm) tend to be fewer in number than at locations where the current annual standard is exceeded.

While it is not possible currently to quantify the margin of safety provided by the existing annual standard, two observations are relevant: (1) a 0.053 ppm standard is consistent with CASAC's recommendation (Friedlander, 1982; Lippmann, 1984) to set the annual standard at the lower end of the range (0.05 to 0.08 ppm) cited in the OAQPS Staff Paper to ensure an adequate margin of safety against long-term effects and provide some measure of protection against possible short-term health effects, and (2) a 0.053 ppm standard would keep annual NO_2 concentrations considerably below the long-term levels for which serious chronic effects have been observed in animals. Maintaining the current annual primary standard is a prudent public health policy choice that will prevent any increased chronic health risk in large, populated urban areas that are now attaining the standard. Consequently, the Administrator has determined that retaining the current primary annual standard of 0.053 ppm is both necessary and sufficiently prudent to protect public health against chronic effects with an adequate margin of safety and provides some measure of protection against possible short-term health effects.

Need for a Short-term Standard

Section 109(c) of the Clean Air Act specifically requires the Administrator to promulgate a primary NO_2 standard with an averaging time of not more than 3 hours unless he or she finds no significant evidence that such a short-term standard is required to protect public health. In conjunction with the review of the annual standard, EPA also has carefully examined the health effects data base to determine whether a separate short-term standard is required to protect public health. As discussed in more detail in the OAQPS Staff Paper and proposal preamble, there are considerable uncertainties about whether short-term (less than 3 hours) exposures to NO_2 at levels observed in the ambient air cause any adverse health effects in humans. Citing these uncertainties, EPA did not propose to set a separate short-term standard and solicited public comment on the need, if any, for a separate short-term standard (49 FR 6866). EPA also requested that public comments on this issue identify any scientific or technical evidence that would support any particular standard level and other relevant elements of the standard, such as averaging time, number of exceedances, and form of the standard.

EPA's assessment of the health effects evidence relevant to any decision on the need for a separate short-term standard and EPA's review of scientific studies that have become available since CASAC closure on the Criteria Document and OAQPS Staff Paper, have been summarized earlier in this RIA in the section, Mechanisms of Toxicity and Nature of Effects, in Chapter IV. More detailed information about EPA's assessment of the scientific evidence pertinent to the short-term standard issue can be found in the Criteria Document, OAQPS Staff Paper, and ECAO's review of recent studies (Grant, 1984).

Public comments on the proposal generally argued for one of the following positions: (1) EPA should propose a short-term primary standard, (2) EPA should conclude that no short-term standard is needed at this time, or (3) EPA should defer its decision on whether a separate short-term standard is needed until results are available from a multi-year research program focused on resolving or reducing the uncertainties surrounding the need for a short-term standard. EPA staff discussed these three options and ECAO's review of the newer scientific studies with the CASAC at the public meeting held on July 19-20, 1984. A transcript of a meeting has been placed in the docket (OAQPS 78-9).

The CASAC, as indicated in its October 18, 1984 letter to the Administrator (Lippmann, 1984), concurred with the EPA staff that the available information was insufficient to provide an adequate scientific basis for decisions on a short-term standard level, averaging time, and number of allowable exceedances which would be required to propose a separate short-term standard. At the same time the CASAC stated that it could not rule out the possibility of adverse health effects at ambient NO_2 levels given the large uncertainties in the scientific data base. CASAC concluded that either of the remaining options, which would not propose to set a short-term standard at this time, were functionally equivalent, i.e., EPA could aggressively pursue scientific research to resolve or reduce the uncertainties about health effects related to short-term NO_2 exposures under either option selected. CASAC recommended that EPA "reaffirm the annual standard at the current level" and that EPA "defer a decision on the short-term standard while pursuing an aggressive research program on short-term effects of NO_2" (Lippmann, 1984).

Given (1) the language on the short-term standard in the Clean Air Act which requires the Administrator to establish a short-term standard unless he or she finds that there is no significant evidence that one is required to protect public health and (2) the large scientific uncertainties remaining about possible short-term effects at ambient NO_2 levels, the Administrator has concluded that it would be prudent to defer a decision on the need for a short-term standard. The Agency is committed to carrying out a focused research program designed to resolve or reduce the major uncertainties associated with the question of whether short-term NO_2 exposures at ambient levels adversely affect public health. In the meantime, the Administrator believes that attainment of the current 0.053 ppm annual standard will provide some measure of protection against possible short-term health effects.

B. WELFARE EFFECTS AND THE SECONDARY STANDARD

As indicated above, section 109(b) of the Clean Air Act mandates the setting of secondary NAAQS to protect the public welfare from any known or anticipated adverse effects associated with an air pollutant in the ambient atmosphere. A variety of effects on public welfare have been attributed to NO_2 and NO_x compounds. These effects include increased rates of acidic deposition, symptomatic effects in humans, vegetation effects, materials damage, and visibility impairment. The OAQPS Staff Paper (OAQPS 78-9, II-A-7) describes in detail each of the welfare effects of concern. The following discussion summarizes the welfare-related effects discussed in the OAQPS Staff Paper, and CASAC's comments relating to the secondary NO_2 NAAQS.

The issue of acidic deposition was not directly assessed in the OAQPS Staff Paper because EPA has followed the guidance which was given by CASAC on this subject at its public meeting review of the draft document, "Air Quality Criteria for Particulate Matter and Sulfur Oxides," which was held on August 20-22, 1980. The CASAC concluded that acidic deposition is a topic of extreme scientific complexity because of the difficulty in establishing firm quantitative relationships between emissions of relevant pollutants, formation of acidic wet and dry deposition products, and effects on terrestrial and aquatic ecosystems. Secondly, acidic deposition involves, at a minimum, the criteria pollutants of oxides of sulfur, oxides of nitrogen, and the fine particulate fraction of suspended particulates. Finally, the Committee felt that any document on this subject should address both wet and dry deposition, since dry deposition is believed to account for at least one-half of the total acid deposition problem. For these reasons, the Committee felt that a significantly expanded and separate document should be prepared prior to any consideration of using NAAQS as a regulatory mechanism for control of acidic deposition. CASAC suggested that a discussion of acidic deposition be included in the criteria documents for both NO_x and particulate matter and sulfur oxides, but that plans also be made for the development of a separate, comprehensive document on acid deposition. In response to these recommendations, EPA is in the process of developing an acidic deposition document that will provide a more comprehensive treatment of this subject.

As defined in section 302(h) of the Act, welfare effects include effects on personal comfort and well being. Mild symptomatic effects were observed in 1 of 7 bronchitics and in 7 of 13 asthmatics during or after exposure to 0.5 ppm NO_2 for 2 hours in the Kerr et al. (1979) study. The authors indicate that the symptoms were mild and reversible and included slight headache, nasal discharge, dizziness, chest tightness and labored breathing during exercise. In EPA's judgment these mild symptomatic effects affect personal comfort and well being and could be considered adverse welfare effects in certain situations. CASAC generally agreed with this judgment, but felt that because short-term peaks associated with these effects are rarely observed in areas where the current annual standard of 0.053 ppm was met, the current annual standard is adequate to protect against these effects.

Evidence in the Criteria Document and information provided by plant physiologists (Heck, 1980; Tingey, 1980a; Tingey, 1980b) have indicated that visible injury to vegetation due to NO_2 alone occurs at levels which are above ambient concentrations generally occurring within the U.S., except around a few point sources. Several studies (Korth et al., 1964; Haagen-Smit et al., 1952; Heck, 1964; Taylor et al., 1975; Thompson et al., 1970) on the effects of NO_2 alone on vegetation have failed to show plant injury at concentrations below 2 ppm for short-term exposures. For long-term exposures, such as a growing season, the lowest concentration reported to depress growth is approximately 0.25 ppm (Korth, 1964). The concentrations which produced injury or impaired growth in these studies are higher than those which would be expected to occur in the atmosphere for extended periods of time in areas attaining a 0.053 ppm annual standard.

In regard to vegetation effects from NO_2 in combination with other pollutants, plant responses to pollutant mixtures appear to vary with concentration, ratio(s) of pollutants, sequence of exposure, and other variables. Studies examining exposure to NO_2 and SO_2 as well as to O_3 and SO_2 (MacDowell and Cole, 1971; Tingey, 1973) have shown that the synergistic response is most pronounced near the threshold doses of the gas combinations tested and that, as concentrations increase beyond the threshold doses, the synergistic response diminishes, often becoming additive, or in some cases, antagonistic. Therefore, although the limited evidence available indicates that low levels of NO_2 and SO_2 can have a synergistic effect, this type of response is extremely variable and has not been sufficiently documented. CASAC concurred with EPA's judgment that the data do not suggest significant effects of NO_2 on vegetation at or below current ambient levels and that an annual standard of 0.053 ppm would provide sufficient protection against significant effects on vegetation.

In regard to visibility impairment due to NO_2, the scientific evidence indicates that light scattering by particles is generally the primary cause of degraded visual air quality and that aerosol optical effects alone can impart a reddish brown color to a haze layer. Thus while it is clear that both particles and NO_2 contribute to brown haze, the CASAC concurred with EPA's judgment that the relationship between NO_2 concentrations and visibility impairment has not been sufficiently established and that a separate secondary standard to protect visibility is not warranted at this time. CASAC confirmed this judgment at its public meeting held on July 19-20, 1984.

Finally, while NO_2 has been qualitatively associated with materials damage, CASAC concurred with EPA's judgment that the available data do not suggest major effects of NO_2 on materials for concentrations at or below the current annual standard of 0.053 ppm.

Based on an evaluation of symptomatic effects, vegetation damage, visibility impairment, and materials damage, and the levels at which these effects are observed, it is EPA's judgment that the current annual standard provides adequate protection against both long- and short-term welfare effects and that there is no need for a different secondary standard. For these reasons, EPA is retaining the secondary standard at the same level as the primary standard.

VIII. STATUTORY AUTHORITY

The statutory authority for the retention of the annual NO_2 NAAQS is contained in the Clean Air Act. Two sections of the Act govern the establishment and revision of NAAQS. Section 108 (42 U.S.C. 7408) requires EPA to document the most recent scientific information (criteria) on the health and welfare effects of certain air pollutants. Section 109 provides authority for establishing and revising primary (health based) and secondary (welfare based) NAAQS. A more complete discussion of the legal authority for this action is contained in the promulgation preamble.

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TECHNICAL APPENDIX A
TO
CHAPTER VI
OF THE
NO_2 NAAQS REGULATORY IMPACT ANALYSIS

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PART ONE

AN EVALUATION OF SELECTED STUDIES DERIVING DAMAGE FUNCTIONS OF NO_2 EFFECTS

I. INTRODUCTION

This section examines studies found in the Criteria Document for their possible use in constructing damage functions. By far the most emphasis is placed on epidemiological studies of the human health effects of NO_2 exposures. Both "outdoor" and "indoor" (or gas stove) studies are reviewed and, where feasible, physical damage functions are derived from the published data. Less detailed discussions follow of the materials and vegetation effects of NO_2. Finally, a section is included that reviews several valuation studies that do not appear in the Criteria Document, including studies on textile damages from NO_2 and several "property value" studies which relate housing price differentials to variation in ambient NO_2 levels.

II. HUMAN HEALTH DOSE-RESPONSE FUNCTIONS

Controlled human exposure studies, community exposure studies, and animal studies have been used to investigate health effects to humans arising from NO_2 exposures. However, only the community exposure studies provide the kind of information necessary to construct dose-response functions. Unless one is prepared to quantify the relationship between animal and human response to a given dose (or to equivalent doses adjusted for metabolic rates, body weight, and other factors), the animal studies cannot be used to quantify human health effects.

It is also difficult to use controlled exposure studies in the Criteria Document for this purpose, for several reasons. First, the studies measure adverse effects in ways that do not readily translate into quantifiable health effects. How does an increase in airway resistance, a reduction in the diffusion capacity of the lung, an increase in sensitivity to a bronchoconstrictor, or a decrease in pulmonary function, relate to how an individual feels or how his or her daily life or life span has changed? While contingent valuation and other behavioral response techniques can be used to assess values of such effects, time and resource constraints precluded the use of these techniques for this project.

The controlled experiment studies reviewed here also have flaws that impair their credibility. Many ignore the standard laboratory procedure of using control groups. The Orehek study (1976), for instance, failed to establish a group of individuals that used the inhalation device but inhaled "air" without NO_2 or with NO_2 at background levels. Other researchers exposed their subjects to NO_2 concentrations far in excess of "normal" ambient concentrations. While it is recognized that the use of such high concentrations may be necessary in the interest of saving research time and money, any adverse effects discovered by this technique must be extrapolated to ambient concentrations before likely "field" responses can be quantified. Such extrapolations must be arbitrary to some degree.

Two types of community exposure studies are reviewed in the Criteria Document--"outdoor" studies and "indoor" studies. Curiously, the outdoor studies make no attempt to correct for variability in indoor exposure; while the indoor studies usually fail to correct for differences in outdoor NO_2 concentrations.

A. OUTDOOR EPIDEMIOLOGICAL STUDIES

All of the "outdoor" epidemiological studies listed in the Criteria Document that attempt to link ambient NO_2 concentrations with various health effects have been reviewed.

1. Hickey et al. (1970).

This study used aggregate data from 38 SMSAs to investigate possible links between mortality rates in 1960 for various diseases (chiefly cancers and heart disease) and ambient concentrations of NO_2, SO_2, sulfates and twenty trace metals in ambient air. Using multiple regression, this study found NO_2 concentrations to be a significant predictor of mortality rates for breast cancer, respiratory system cancer, lung cancer, urinary organ cancer, stomach cancer, and arterioschlerotic heart disease. NO_2 also entered the equations for congenital malformations and total deaths under one year, but with the wrong sign. No significant results for bronchitis were found.

Unfortunately, this study is afflicted with such severe methodological difficulties that the results are questionable. First, almost all regressions are stepwise, with variables being selected only on the basis of their contribution to R^2. In addition, the only explanatory variables are the pollution variables, even though variables such as population density, median age, and per capita income would be likely to affect disease rates. The fact that NO_2 significantly enters most of the cancer incidence equations tends to support Hickey's contention that NO_2 is a carcinogen, but this fact could have been accounted for by correlations among the cancer rates. Unfortunately, Hickey et al. do not report the correlation matrix for the dependent variables.

2. Stebbings and Hayes (1975).

Over 300 persons aged 60 living in three neighborhoods of New York City participated in a study of the acute effects of air pollution on symptoms of heart and lung disease. The panel contained some healthy individuals as well as some with reported cardiopulmonary symptoms. This study is unusable for several reasons: (i) because NO_2 measurements were made with the Jacobs-Hochheiser technique, NO_2 was dropped from the study, (ii) the number of pollutants examined greatly exceeded the number of sites where pollution was measured. Therefore, effects of individual pollutants could not be isolated.

3. Chapman et al. (1973).

This article is a survey of the CHESS studies. Only one of the studies mentioned examined NO_2 exposure--a survey of 3,500 adults in Chattanooga in 1970. No significant differences in respiratory disease symptoms were reported. However, the Jacobs-Hochheiser method was used to calculate NO_2 concentrations; hence the result is called into question.

4. Linn et al. (1976).

Office workers in San Francisco and Los Angeles were examined for differences in respiratory disease symptoms. Only minimal differences were found. In any event, no difference could be ascribed to NO_2 because of other pollutants, chiefly oxidants and particulates.

5. Kagawa and Toyama (1975).

Lung function of 21 elementary school children was correlated with daily concentrations of oxidant, ozone, hydrocarbon, NO, NO_2, SO_2, and particulates. NO_2 varied between 0.01 and 0.08 ppm. Only pairwise correlations were reported. NO_2 was significantly correlated with maximum expiratory flow rates for only two children ($p < .05$). Since no multivariate analyses were performed, the results are difficult to interpret. Nonetheless, it does not appear that NO_2 concentrations had an acute effect on lung function, at least in the range experienced. Besides, since the study does not relate lung function to disease, a dose-response function that could lead to benefit valuations is difficult to derive without using contingent valuation or other behavioral response techniques.

6. Cohen et al. (1972).

This study looked for differences in respiratory disease incidence among Seventh Day Adventists in the San Gabriel Valley and San Diego. (Seventh Day Adventists were chosen because very few of them smoke.) No significant differences in respiratory symptoms were found. As in the Linn study, NO_2 concentrations are correlated with ozone and particulates, making it difficult to isolate effects of particular pollutants.

7. Petr and Schmidt (1966).

This study examined prevalence of disease symptoms (including enlarged tonsils and lymph glands and lymphocyte count) and respiratory function of children in two urban areas of Czechoslovakia. The study areas included a control area, a high NO_2-low SO_2 area, and a high SO_2-low NO_2 area. Most of the effects were reported for the high-NO_2 area. This study is unsuitable because only pollutant ranges were reported, and these ranges varied by a factor of up to ten.

8. Kalpazanov et al. (1976).

This study attempted to determine whether daily air pollution readings were related to registered instances of influenza in Sofia, Bulgaria during an epidemic in December 1974-February 1975. Unlike the other epidemiological studies examined, this one used multivariate regression. Repeated illnesses were regressed against meteorological and pollution variables with 0, 1, and 2-day lags. While the regressions were reported to have significant F-values, the standard errors of the estimated coefficients were not given. Nor was the correlation matrix. The mean values of the independent variables were given (21 ug/m^3 for NO_2), but not the standard deviations. Thus, the results are of questionable validity. Considerable doubt is thrown on their results by the fact that oxidants entered the equations with the wrong sign.

9. Shy et al. (1970) and Pearlman (1971).

As part of the CHESS studies, groups of elementary school children and infants in the Chattanooga area were examined in an effort to determine the effects, if any, of long-term exposure to ambient concentrations of NO_2. Chattanooga was selected for these studies because it is the site of a large stationary source of NO_2 (a TNT plant); several neighborhoods in threa were then selected to give an NO_2 exposure gradient. School children, infants, and their parents were then tested for lung function and surveyed to determine respiratory disease incidence. These studies have been severely criticized for defects of analytical and chemical procedure. In particular, the NO_2 concentration measurements were made by the Jacobs-Hochheiser method, which has since been shown to be affected by other constituents of the air. Also, concentration measurements were made for only a six-month period (Oct. 29, 1968 to April 26, 1969), yet these were matched with respiratory disease data spanning a three year period. In addition, the statistical techniques used in these studies were not appropriate to the estimation of does-response functions (nor was that their purpose).

In Pearlman, et al. (1971), frequencies of bronchitis, croup, and pneumonia among infants and school children in three neighborhoods were related to ambient concentrations of NO_2. For each disease, a table of illness frequency (percent of children reporting one or more disease episodes) versus average pollutant concentration and years of exposure was given. Chi square tests were then used to find disease rates that were different from what would be expected in the absence of a pollution gradient. Table 1 shows the bronchitis frequencies reported by Pearlman, et al. They concluded that "one or more episodes of bronchitis were reported significantly more often by school children residing for two ($p = 0.02$) and three ($p = 0.01$) years in the high and intermediate NO_2 areas. This pattern was not consistent for infants."

Table 1

Percent of Children Reporting One or More Incidents
of All Lower Respiratory Illness

NO_2 Concentration (ppm)	School Children years of exposure 1	2	3	Infants years of exposure 1	2	3
0.083	20.9	34.7	32.2	33.3	37.5	46.8
0.063	31.6	45.5	31.2	26.2	29.5	50.5
0.043	25.1	20.3	23.2	21.1	34.0	36.3

The nine data points on the table allow a two-variable regression equation to be constructed.

The model is

$$\ln p/(1-p) = a + b_{NO2}\, C(NO_2) + b_t t + u,$$

where p is the tabular entry (expressed as a fraction), $C(NO_2)$ the NO_2 concentration in ppm, and t the time of exposure in years. For school children, the results are

$$\ln p/(1-p) = -\,0.96 + \underset{(6.44)}{5.47}\, C(NO_2) + \underset{(0.129)}{0.073}\, t$$

Neither coefficient is significant. (Standard errors in parentheses.)

For infants, the results are as follows:

$$\ln p/(1-p) = -\,1.60 + \underset{(2.18)}{8.47}\, C(NO_2) + \underset{(0.044)}{0.42}\, t$$

These results are significant for infants but not for school children, which is the reverse reported by Pearlman on the basis of a chi-square test.

One problem with the study was the high correlation between particulates and NO_2 ($r = 0.999$). Moreover, the particulate concentrations varied over a range in which a health response cannot be ruled out.

The second report from the Chattanooga study, Shy et al. (1970), allows the relative importance of NO_2 and particulates to be investigated. This report includes illness from a fourth area, a "high particulate" area, with NO_2 concentrations of 0.055 ppm and particulate concentration of 99 ug/m^3. In each area Shy reports the rate of respiratory illness (number of illnesses per 100 persons per week) for second graders, their siblings, mothers, and fathers. The study uses statistical methods similar to Pearlman et al., and concludes that NO_2 significantly affects illness rates for some population groups. However, when the illness rate is regressed on NO_2 and particulates, while controlling for the individual's status in the family, the following results are obtained:

Variable	Parameter Estimate	Standard Error
Intercept	7.03	2.67
Second graders (0-1)	9.70	1.07
Siblings (0-1)	5.28	1.12
Mothers (0-1)	2.86	1.23
NO_2 (ppm)	-1.86	2.94
Particulate ug/mg^3	0.058	0.030

The particulate variable is significant at the ten percent level and has the right sign; NO_2 is insignificant and has the wrong sign.

Shy, et al also adjusted their illness rates to account for family size and sibling order by regressing illness rates on these two variables and using the regression coefficients to adjust illness rates. If the adjusted illness rates are regressed on the five variables above, the results are as follows:

Variable	Parameter Estimate	Standard Error
Intercept	3.43	2.50
Second graders	9.88	1.06
Siblings	6.63	1.06
Mothers	3.20	1.06
NO_2	3.28	2.67
Particulates	0.060	0.029

NO_2 now has the right sign, but is still not significant.

In view of the inaccuracies of the Jacobs-Hochheiser method, these results are probably not reliable. They are reported to illustrate how the use of alternative and more appropriate statistical procedures can completely alter the results of epidemiological studies.

10. Shy and Love (1979).

A new study of the link between NO_2 and respiratory disease was made in 1972 and 1973 by Shy and Love. From January to May in each of these years, data on respiratory disease frequency was obtained from the same neighborhoods in Chattanooga as in the earlier study. These data were matched against pollution measures made during the same years. The Saltzman method was used for measuring NO_2. Sufficient data are given in the report to use regression analysis to relate disease frequency to pollution concentrations. Regressions analysis of the data in fact showed that elevated NO_2 concentrations were associated with increased acute respiratory disease incidence in preschool children. However, subsequent to the data analysis, errors were found in the data reported by Shy and Love. The most serious is that personal illness rates of one period were matched with NO_2 concentrations from another period. Thus, the regression results are invalid and are not appropriate for use as dose-response functions.

11. Shy et al. (1973).

After the biases of the Jacobs-Hochheiser method became known, Shy et al. attempted to retrieve the situation using an NO_2 data base compiled in 1967-1968 as part of an interstate air quality study for Chattanooga and Rossville, Ga. The monitoring stations used for this study were not, of course, located at the same sites used by the Shy study. Figure 1 shows the relationship between the monitoring network of the interstate study and the neighborhoods of the Shy study. In Figure 1, the circled numbers are monitoring stations. H1, H2, H3 are the three elementary schools in the "high NO_2" area, and C1, C2, and P are respectively, the "intermediate NO_2," "low NO_2" and "high particulate" areas. "VAAP" is the Volunter Army Ammunition Plant, the high-NO_X source.

In their report (Shy, 1973), the researchers attempted to use the 1967-1968 monitoring data to construct isopleths of NO_2 ambient concentration at the 90th percentile. The report does not indicate the method used to generate the isopleths. These isopleths are shown in Figure 2. Concentrations at each site could then be estimated by their location relative to these isopleths, e.g., concentration in the high-particulate area is between 0.05 and 0.10 ppm. For a point estimate one can take a linear interpolation based on the distance between the isopleths.

Alternatively, concentrations in all the neighborhoods except C2 can be estimated by averaging concentrations from appropriate monitoring stations. This procedure allows estimation of tne mean concentrations as well as the 90th percentile hourly concentrations.

Figure 1

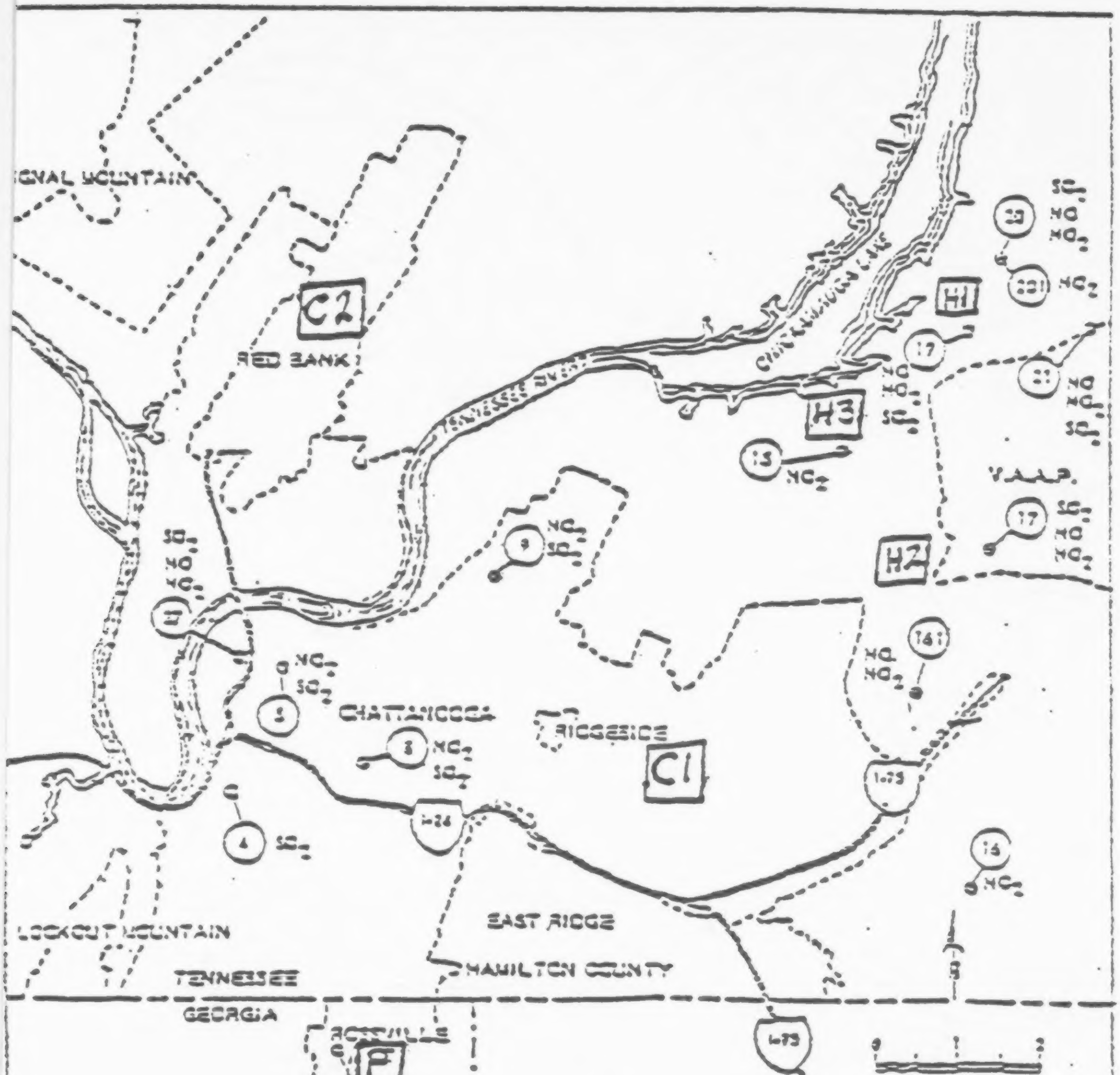
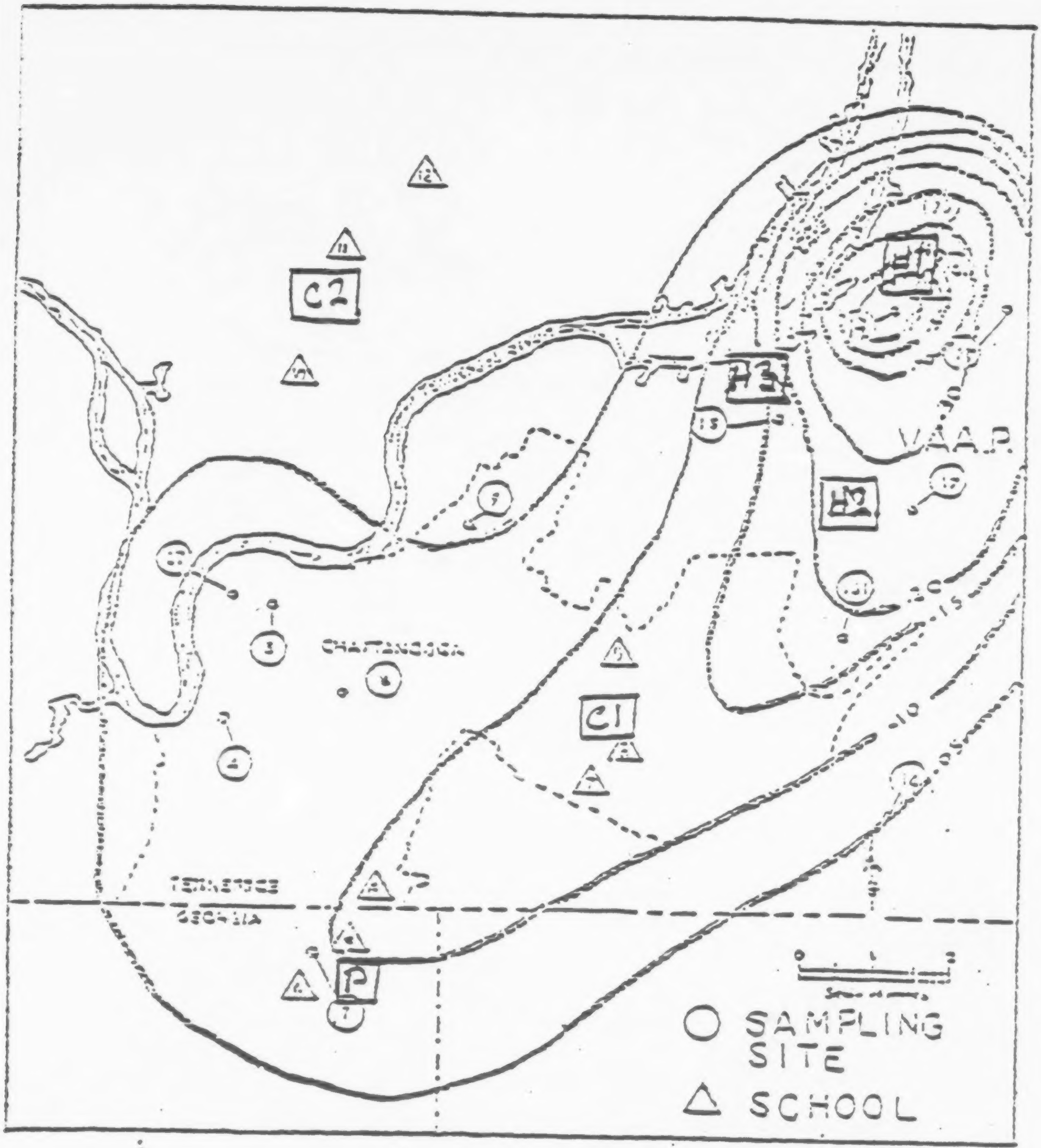

SIGNAL MOUNTAIN
C2
RED BANK
TENNESSEE RIVER
CHICKAMAUGA LAKE
H1
H3
H2
C1
F
V.A.A.P.
CHATTANOOGA
RIDGESIDE
LOOKOUT MOUNTAIN
EAST RIDGE
HAMILTON COUNTY
TENNESSEE
GEORGIA
ROSSVILLE
WALKER COUNTY
CATOOSA COUNTY
I-24
I-75
I-75
SO2 NO NO2
NO NO2 SO2
NO2
NO2 SO2
NO2 SO2
SO2
NO NO2
NO2
NO2 SO2
Scale of miles
0 1 2

Figure 2


C2
H1
H3
H2
VAAP
CHATTANOOGA
C1
TENNESSEE
GEORGIA
P
20
15
10
05
SAMPLING SITE
SCHOOL

CHATTANOOGA NO_2 ISOPLETH
90th PERCENTILE HOURLY AVERAGES

Table 2 compares the estimates of 90th percentile concentrations made using the two procedures described above with the concentrations determined by the Jacobs-Hochheiser method in the original study. For the Saltzman data, isopleth interpolation and the averaging of nearest monitors give results that agree closely. The observations based on Jacobs-Hochheiser, however, are considerably less than the Saltzman data for H1, H2, H3, and C1 and slightly less for P. No comparison is possible for C2, although Shy believes the concentration in C2 to be less than 0.05 ppm (see Table 6 in Shy (1973a)). The difference in concentrations for the two methods is attributable either to a difference in measurement methods or to the fact that readings were taken in different years. The difference in measurement periods could cause differences in ambient NO_2 readings only if there was a difference in NO_2 emissions from the plant or if there was a difference in meteorological conditions. However, neither of these conditions seems to hold. Production at the VAAP in 1969 was four percent less than in 1968 (Shy, 1973a, Table 3), not enough to account for the difference in readings. Differences in meteorological conditions would presumably affect other pollutants. However, concentrations of TSP, sulfate and nitrates taken in downtown Chattanooga show no dramatic decrease from 1968 to 1969; in fact, nitrate concentrations increase substantially (Hasselblad, 1977).

Therefore, it can be concluded that ambient concentrations in 1968 and 1969 were roughly the same, and that reported differences are attributable to the measurement methods. In view of the reported difficulties of the Jacobs-Hochheiser method, it appears that the Saltzman readings are the more accurate estimates of NO_2 concentrations in 1969.

The NO_2 concentrations given in Tables 2 and 3 can now be used to explain incidence of respiratory disease among children in Chattanooga. The OLS

Table 2

Estimated Concentrations At Six Chattanooga Study Sites, 1968-9
Comparison of 90th Percentile Values
(ppm)

Sampling Period	Jacobs Hochheisser[a] 10/68 - 4/69	Saltzman (4/67 - 11/68) Isopleth Interpolation[b]	Average Values From Nearest Monitors Concentration[c]	Monitors Used
Site				
H1	0.242	0.55	0.54	20,201,19
H2	0.141	0.23	0.20	15,17,161
H3	0.098	0.15	0.16	15
C1	0.096	0.13	0.10	16,161,5[d]
C2	0.069	0.05	-	
P	0.087	0.09	0.09	7

---

a. Data from Shy et al. (1970b)

b. Data from Shy (1973a). Computed from linear interpolation of isopleths on Figure 2.

c. Data from Shy (1973a). Average of reported values from monitors indicated.

d. No data given for monitors 8,9, or 4; 5 used as surrogate.

Table 3

Estimated Concentrations At Six Chattanooga Study Sites, 1968-9
Comparison of Means
(ppm)

Sampling Period	Jacobs Hochheisser[a] 10/68 - 4/69	Saltzman (9/67 - 11/68) Average Values From Nearest Monitors	
Site		Concentration[c]	Monitors Used
H1	0.019	0.17	20,201,19
H2	0.078	0.09	15,17,161
H3	0.062	0.08	15
C1	0.063	0.05	16,161,5
C2	0.043	-	-
F	0.055	0.04	7

See notes at end of Table 7.

technique is used, although uncertainty about the measurement of NO_2 suggests that the use of the errors in variables model may be appropriate.

Variables are defined as follows:

ILLNESS: Rate of respiratory disease incidence, per 100 person-weeks
SECONDS: 1 if cell refers to second graders, 0 otherwise
SIBS: 1 if cell refers to siblings, 0 otherwise[1]
MOMS: 1 if cell refers to mothers, 0 otherwise
NO_2M: Mean hourly NO_2 concentratrion, ug/m^3
NO_290: 90th percentile of hourly NO_2 concentrations, ug/m^3
PARTICM: Mean hourly particulate concentration, ug/m^3
PARTIC90: 90th percentile of hourly particulate concentrations, ug/m^3

Tables 4 and 5 exhibit the data, means, and standard deviation of the variables, and the correlation matrix. Table 6 gives the coefficients and standard errors for various specifications of the model. In equation 1 both mean and 90th percentile pollutant concentrations are included to see if the effects of mean vs. peak concentrations can be disentangled. However, the high correlations between the mean and 90th percentile concentrations of both pollutants evidently prevented this disentanglement. In the other four equations each NO_2 variable is entered with each particulate variable. In the four equations the pollutant coefficients are fairly stable. The coefficient for mean NO_2 is about four times greater than the coefficient for the 90th percentile. This is expected, for when NO_290 is regressed against NO_2M alone, the resulting equation is

---

[1] SIBS contains data on all siblings of second graders, both older and younger.

Table 4

OBS	ILLNESS	SECONDS	SIBS	MOMS	NO2M
1	23.4000	1	0	0	321
2	19.9000	0	1	0	321
3	15.3000	0	0	1	321
4	11.0000	0	0	0	321
5	23.4000	1	0	0	170
6	18.0000	0	1	0	170
7	14.4000	0	0	1	170
8	12.8000	0	0	0	170
9	20.4000	1	0	0	151
10	19.1000	0	1	0	151
11	13.4000	0	0	1	151
12	12.1000	0	0	0	151
13	10.0000	1	0	0	94
14	15.6000	0	1	0	94
15	11.8000	0	0	1	94
16	8.8000	0	0	0	94
17	21.4000	1	0	0	75
18	16.1000	0	1	0	75
19	16.1000	0	0	1	75
20	11.3000	0	0	0	75

OBS	NO290	PARTICM	PARTIC90	NO2X2ND	NO2XSIB
1	1019	96	183	321	0
2	1019	96	183	0	321
3	1019	96	183	0	0
4	1019	96	183	0	0
5	434	83	138	170	0
6	434	83	138	0	170
7	434	83	138	0	0
8	434	83	138	0	0
9	283	63	108	151	0
10	283	63	108	0	151
11	283	63	108	0	0
12	283	63	108	0	0
13	245	72	128	94	0
14	245	72	128	0	94
15	245	72	128	0	0
16	245	72	128	0	0
17	170	99	181	75	0
18	170	99	181	0	75
19	170	99	181	0	0
20	170	99	181	0	0

Table 4

```
VARIABLE     N          MEAN             STD DEV               SUM             MINIMUM           MAXIMUM

ILLNESS     20      16.11500000       4.24639476        322.30000000        8.80000000       23.40000000
SECONDS     20       0.25000000       0.44426166          5.00000000        0                 1.00000000
SIBS        20       0.25000000       0.44426166          5.00000000        0                 1.00000000
MOMS        20       0.25000000       0.44426166          5.00000000        0                 1.00000000
NO2H        20     162.20000000      89.04026292       3244.00000000       75.00000000      321.00000000
NO290       20     430.20000000     314.68306529       8604.00000000      170.00000000     1019.00000000
PARTICH     20      82.60000000      14.10636288       1652.00000000       63.00000000       99.00000000
PARTIC90    20     147.60000000      30.48105538       2952.00000000      108.00000000      183.00000000
NO2X2ND     20      40.55000000      84.70287076        811.00000000        0               321.00000000
NO2XSIB     20      40.55000000      84.70287076        811.00000000        0               321.00000000

                    CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / N = 20

             ILLNESS  SECONDS     SIBS      MOMS      NO2H     NO290  PARTICH PARTIC90  NO2X2ND   NO2XSIB

ILLNESS      1.00000  0.72607  0.22668 -0.26713  0.20933  0.18702  0.15457  0.13688  0.70201  0.28338
              0.0000   0.0003   0.3365   0.2549   0.3757   0.4298   0.5153   0.5650   0.0006   0.2260

SECONDS      0.72607  1.00000 -0.33333 -0.33333  0.00000  0.00000  0.00000  0.00000  0.85073 -0.28358
              0.0003   0.0000   0.1510   0.1510   1.0000   1.0000   1.0000   1.0000   0.0001   0.2257

SIBS         0.22669 -0.33333  1.00000 -0.33333  0.00000  0.00000  0.00000  0.00000 -0.28358  0.85073
              0.3365   0.1510   0.0000   0.1510   1.0000   1.0000   1.0000   1.0000   0.2257   0.0001

MOMS        -0.26713 -0.33333 -0.33333  1.00000  0.00000  0.00000  0.00000  0.00000 -0.28358 -0.28358
              0.2549   0.1510   0.1510   0.0000   1.0000   1.0000   1.0000   1.0000   0.2257   0.2257

NO2H         0.20933  0.00000  0.00000  0.00000  1.00000  0.98052  0.27545  0.34242  0.26280  0.26280
              0.3757   1.0000   1.0000   1.0000   0.0000   0.0001   0.2398   0.1394   0.2630   0.2630

NO290        0.18702  0.00000  0.00000  0.00000  0.98052  1.00000  0.40181  0.47355  0.25768  0.25768
              0.4298   1.0000   1.0000   1.0000   0.0001   0.0000   0.0791   0.0349   0.2727   0.2727

PARTICH      0.15457  0.00000  0.00000  0.00000  0.27545  0.40181  1.00000  0.98032  0.07239  0.07239
              0.5153   1.0000   1.0000   1.0000   0.2398   0.0791   0.0000   0.0001   0.7617   0.7617

PARTIC90     0.13688  0.00000  0.00000  0.00000  0.34242  0.47355  0.98032  1.00000  0.08999  0.08999
              0.5650   1.0000   1.0000   1.0000   0.1394   0.0349   0.0001   0.0000   0.7060   0.7060

NO2X2ND      0.70201  0.85073 -0.28358 -0.28358  0.26280  0.25768  0.07239  0.08999  1.00000 -0.24125
              0.0006   0.0001   0.2257   0.2257   0.2630   0.2727   0.7617   0.7060   0.0000   0.3055
```

Regression Results: Relationship Between Pollution and Illness
Chattanooga in 1969
Dependent Variable: Illness

Equation	Intercept	Seconds	Kids	Moms	NO2M	NO290	ParticM	Partic90	F	R2
1	-1.26 (2.91)	10.12 (0.76)	6.56 (0.75)	3.00 (0.023)	0.076 (0.037)	-0.019 (0.109)	0.191 (0.056)	-0.048	31.9	0.92
2	5.10 (2.81)	10.12 (1.03)	6.56 (1.05)	3.00 (1.07)		0.0020 (0.0014)		0.0087 (0.0014)	20.1	0.83
3	7.98 (2.44)	10.12 (1.07)	6.56 (1.07)	3.00 (1.07)		0.0020 (0.0014)	0.028 (0.030)		21.0	0.84
4	8.26 (1.98)	10.12 (1.04)	6.56 (1.04)	3.00 (1.04)	0.0087 (0.0045)			0.010 (0.013)	22.3	0.85
5	7.20 (2.28)	10.12 (1.02)	6.56 (1.02)	3.00 (1.02)	0.0086 (0.0043)		0.032 (0.027)		23.6	0.86

$$NO_2 90 = -132 + 3.5\ NO_2 M, \quad R^2 = 0.96.$$

Based on F values, adjusted R squares and the fact that equation 1 exhibits evidence of multicollinearity, the model that seems to most closely fit the data is equation 5. Here the NO_2 coefficient is positive and significant at the ten percent level. However, these results must be viewed with caution since the concentration values are from an independent air quality study conducted earlier than the respiratory disease survey.

12. Conclusions

As was shown above, the 1968-69 Chattanooga survey data cannot be used to develop dose-response functions because NO_2 concentrations were measured using the Jacobs-Hochheiser method. While the reanalysis of the 1968-69 data using interstate air quality survey data supports the Shy and Love contention that higher levels of No_2 are associated with increased respiratory disease incidence, the dose-response functions are of questionable value since the air quality data used are from different locations and time periods than the respiratory disease data. Finally, the 1972-73 regression results are of no use because of the reporting error in the study from which the data were taken. However, further analysis of the 1972-73 data may lead to credible dose-response functions for benefit analysis. Such an effort was not undertaken here due to project time and resource constraints.

B. INDOOR EPIDEMIOLOGICAL STUDIES

All of the available "gas stove" studies were reviewed for their usefulness in the construction of dose-response functions. Two studies by Melia et al. (1977 and 1979a) and two studies by Speizer et al. (1980 and forthcoming) may be useful in this regard. As these studies only investigate the link between gas/electric stove use and health, studies that measured exposures to NO_2 in homes with gas or electric stoves were also reviewed.

1. Keller (1979)

Keller (1979), in a study sponsored by the American Gas Association, analyzes data from 441 families from a suburb of Columbus, Ohio, and 146 Long Island households. Lutz (1977) extends this study somewhat. Mitchell (1974) and Lutz et al. (1974)--cover the same material as Keller (1979) and Lutz (1977). Keller finds no association between cooking fuel and respiratory disease. His study is flawed because it uses symptom variables such as chronic lung disease, presence of cough, and presence of asthsma as explanatory variables, thereby obscuring any possible relationship between NO_2 and respiratory disease. Further, the "children" subgroup used by Keller was "less than 12 years old." Critical information is lost by this aggregation. Speizer (1980) found effects of NO_2 only in children under 2, and Melia (1979a) found larger NO_2 effects for children under 8 and, in a separate study, declining effects as a child grows older. Thus, the Keller study offers only the weakest contradictory evidence to Melia and Speizer.

However, one objection to Keller (1979) made by Speizer (1980) does not hold up. Speizer states that Keller's sample size is too small to pick up any NO_2 effects. This statement is merely a truism because any increase in sample size narrows the sample variance. In fact, Keller found no difference (as opposed to no statistically significant difference) between incidence rates in gas and electric stove homes. Thus, increasing the sample size, assuming mean incidence rates remained unchanged, would make no difference in Keller's result. Only if bias in Keller's sampling technique could be shown could his result be questioned on this statistical point.

2. Lutz (1977)

Lutz (1977) repeats Keller's earlier work using 120 of the 441 Columbus households and addresses problems with the reporting of respiratory illness by subjects in the original study. Lutz (1977) comes to the same conclusions as Keller (1979) and validates the ability of subjects to report accurately on respiratory illness.

3. Melia (1977), and (1979a), and (1979b).

From 1973-1978, Melia et al. conducted three studies of the relationship between NO_2 exposures in the home and respiratory disease in children. Melia (1977) reported on respiratory disease incidence from a sample of 5,758 children aged 6 to 11 years from 28 randomly selected areas of England and Scotland. The presence of a gas or electric stove in the home served to differentiate NO_2 exposures while respiratory disease rates were obtained from a questionnaire filled out by parents.

Information about episodes of bronchitis and asthma and the experience of respiratory symptoms over the previous 12 months was requested. What appears to be Chi-square tests were performed on sub-populations divided on the basis of age, sex, social class (occupation), latitude, and urbanization. Other factors--number of siblings, overcrowding, smoke, and SO_2 levels--were also used to explain respiratory rates but small sub-sample sizes led to more inconclusive results.

Melia (1979a) reported on an analysis of respiratory disease incidence in children from the 1973 study through 1977. Data on 2,408 children were available for all five years. In addition, the 1973 study was replicated for 4,827 different children aged 5 to 10 from 27 randomly selected areas in England and Scotland. It appears that these areas are identical to those in the 1973 study. The replication added variables on the presence of a gas water heater, the use of pilot lights, smoking habits, and the number of bedrooms per person.

Melia et al. (1979b) took a different tack by actually measuring mean weekly NO_2 levels in the home (kitchen and bedroom) and relating this measure not only to respiratory disease but also to lung function. Adding lung function as a dependent variable is important because it is primarily through changes in lung function that respiratory disease rates may be affected. Five hundred twenty-seven children aged 6-7 years were included. The confounding factors of age, sex, class, and smoking were included.

Data reporting was sufficient in Melia (1977) and Melia (1979a) to conduct multivariate analysis by transforming incidence rates in each cell to log - odds ratios. Regressing incidence rates on dummy variables for age, sex, social class and presence of gas or electric stove yielded significant results (at the 95 percent level) for all four variables in Melia (1979a), including the gas/electric stove dummy variable. Variables in parentheses are standard errors:

$$\underset{(.077)}{\text{Illness} = -1.169} + \underset{(.069)}{.213\ NO_2} + \underset{(.069)}{.212\ \text{CLASS}} - \underset{(.069)}{.490\ \text{AGE}} + \underset{(.069)}{.258\ \text{SEX}}$$

$n = 16$

$r^2 = .88, F = 20.8$

where

Illness = ln P/1-P, P = percent of sub-sample with respiratory disease

NO_X = 1 for gas stove

AGE = 1 for 8 years old or older

CLASS = 1 for manual labor

SEX = 1 for male

The other variables in Melia (1979a) are of expected sign with younger children showing greater illness incidence than older children and children with parents in manual labor showing greater incidence than those with parents in non-manual labor.

The results for regressions using data in Melia (1977) tell a similar story with regard to NO_X and CLASS, but AGE and SEX are insignificant. The coefficient on NO_X in the 1977 study is nearly double that in Melia (1979a). The regression results using data from Melia (1977) are:

$$\begin{array}{lccccc} \text{ILLNESS} = & -1.249 & + .331\ NO_X & - .271\ \text{AGE} & + .394\ \text{CLASS} & - .023\ \text{SEX} \\ & (.145) & (.129) & (.129) & (.129) & (.129) \end{array}$$

$n = 16$

$r^2 = .65,\ F = 5.05$

Because both of the Melia studies found significant differences in health effects between the sexes, separate regressions were run for boys and girls using data from each study. The NOX relationship to illness is significant for boys, not girls, a finding at variance with Melia (1977), where significant effects for both sexes (larger for girls) were reported. The regression results are troublesome because girls (at least the older ones) may spend more time in the kitchen and, therefore, should be exposed to greater NO_X levels than boys.

The results for the Melia studies suggest that they may be useful for constructing dose-response functions. However, many qualifications should be emphasized. Neither Melia study distinguished between homes using coal (town) gas, natural gas, or propane. The constituents of these gases may differ greatly. In 1973, the data collection year of the 1977 study, some children in the study areas were exposed to both coal and natural gas. Melia notes that a changeover from the former to the latter fuel was taking place in 1973 in most study areas. As the 1979 study surveyed children from the same areas in 1977, it may be presumed that this problem is less significant in the later study.

Another problem concerns the specification of the respiratory disease or symptom variable in both studies. Parents were asked to recall chronic disease symptoms over the previous 12 months. A "chronic" symptom was defined as one that "usually" appeared, but the definition of "usually" was left to the respondant. If no chronic symptoms were present, the variable took a value of "1." It took a value of "2" when a chronic chest cold, wheeze, or cough was observed, or when the subject had asthma, bronchitis, or other respiratory illness. It took a value of "3" if two of these chronic symptoms were observed, and a value of "4" if more than two were observed. In the econometric work reported above, a dummy variable for presence or absence of symptoms or disease was used because it is unclear that a person is more incapacitated with, for instance, a chest cold and a wheeze than only a chest cold.

There are additional problems with using the results of the regressions reported above. To derive a dose-response function from this information, one first would need to interpret how parents defined "usually," as in whether the child "usually" coughed in the morning. Then, from this definition, some quantitative measure of sickness--e.g., the number of sick days--would have to be constructed. It is unclear how these tasks could be performed non-arbitrarily.

Moreover, the above regressions ignore many of the variables tested by Melia as well as some important variables that were not introduced, e.g., ambient NO_2, and humidity and temperature in the home. The indirect NO_2 measure (i.e., gas vs. electric stove use) is extremely crude and, of course, no actual measurements of NO_2 were taken. Further, as reported by Melia, the significance of the NO_x-disease relationship appears to fall off as more variables are added.

In addition, the longitudinal study, Melia (1979a), casts some doubt on the significance of childhood respiratory illness to health in later years: the NO_x effect tended to disappear as the children grew older.

The third Melia study (1979b) also damages the credibility of results from the other two. This better-constructed study found no association between impaired lung function and measured NO_2 in homes. Similarly, no association was found between NO_2 in kitchens and respiratory disease symptoms. However, the hypothesized association did arise with NO_2 measured in the bedroom.

At the end of this third paper, the authors note that "quantitative conclusions about the exposure-response curve should not be drawn from the statistically weak associations in this paper," (p. 352). However, no similar comment accompanies the Melia (1977) or (1979a) papers.

4. Speizer et al. (1980).

Speizer et al. (1980) reported on a study of respiratory disease symptoms, lung function, and indoor NO_2 exposures using a sample of 8,120 white children 6-10 years old from six U.S. cities. Interactions between disease, age, sex, city, social status (2-way), air conditioning, parental smoking, and cooking fuel (gas vs. electric) were investigated using a variety of techniques, including a multi-variate estimation procedure with unreported results. Questionnaires on child health history were used to specify the respiratory symptom variables: history of bronchitis, serious respiratory disease before age 2, and respiratory illness in the past year. Lung function related to cooking fuel, heating fuel, air conditioning, and smoking was analyzed, using ANOVA.

Statistics on the likelihood of having a serious respiratory disease before age 2 have been obtained from the authors of Speizer et al. (1980). Only this illness variable showed significant association with type of stove. Correcting for smoking, sex, and social class, a child in a gas stove home was 20 percent more likely to have a serious respiratory disease before age 2 than one in an electric stove home.

In a separate portion of the study, which supports the significant results reported above, lung function was found to be significantly affected by cooking fuel, city-cohort, and home heating fuel. However, two anomalies appeared--the sign on smoking was reversed and significant, and residents of Topeka had a particularly low level of pulmonary function.

The results themselves are suspect for the usual reasons: no ambient NO_2 or other pollutant measures, no in-house measures of NO_2, no family disease history, a crude social status variable, and crude symptom variables (although less crude than in Melia).

5. Speizer (forthcoming).

In response to criticisms about variable specifications in the Speizer (1980) paper, certain refinements of that study were made. Of most importance, the social class variable was further subdivided into six classes (from two): three levels of educational status (junior high school, high school, college) crossed with "father present/absent." The results of the study have not yet been released but the authors have said that the disease frequency differential, while still significant, is now only seven percent, down from 20 percent in the 1980 study.

6. Comparing Melia et al. to Speizer et al.

Unfortunately the Melia et al. and Speizer et al. results are not directly comparable, primarily because Melia focused on respiratory disease or symptoms in the previous year, while Speizer focused on parents' memories of respiratory disease in their children before they were 2 years old. Speizer ran a multivariate test on a variable identical to Melia's but found that only smoking explained any of its variance. Melia's results could be made somewhat more comparable to Speizer's by running the Melia regressions only with the data for children under 8 years old. Unfortunately, Melia does not have an age category for children under 2.

C. INDOOR EXPOSURE STUDIES AND "INDOOR" DOSE-RESPONSE FUNCTIONS

In this subsection, studies that estimate NO_2 emissions from gas stoves and those that compare emissions from homes with gas or electric stoves are reviewed. First, the use of such information to derive a dose-response function from the Melia studies is discussed.

The coefficient on the gas/electric dummy variable (NOX) in the Melia regressions is the difference in frequency of respiratory disease associated with living in a gas vs. an electric home. For Melia (1979a), the coefficient of 0.21 implies that the frequency of respiratory disease is 55 percent higher among children living in a house with a gas stove than in a house with an electric stove.[1] If the difference in NO_2 concentrations is Xpphm, then, for every pphm change respiratory disease frequency increases by 55/X percent.

For the regressions on data in Melia (1977), where the coefficient on the gas/electric dummy is 0.33, the frequency of respiratory disease and symptoms would be 60 percent higher in gas stove homes, and 60/X percent higher per pphm increase in NO_2 concentrations.

1. Indoor NO_2 Measurement Studies.

A value for X should be estimated in the context of a multi-variate model where differences in indoor NO_2 readings are explained by many variables, among them whether the stove uses electricity or gas. Not surprisingly, no researchers have made such a study, although Melia (1979c) mentions her attempts to correct for confounding factors. One group of researchers (Traynor and Hollowell, 1978), report a convincing inverse relationship between ventilation (air exchange rates) and NO_2 concentrations in a test kitchen, but consider only kitchens with gas stoves. Indeed, most studies examine the NO_2--gas stove relationship while ignoring homes with electric stoves. Unless it is assumed that NO_2 in electric stove homes matches ambient levels (as suggested by Speizer (1980)) and reliable ambient values for NO_2 concentrations corresponding to the areas studied can be obtained, the studies that focus only on NO_2 measurements in gas stove homes cannot be used.

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[1] Computed by taking $\frac{\partial \log \frac{p}{1-p}}{\partial NOX} = \hat{B}$, and solving for $\partial p/\partial NOX$.

The literature cited in the Criteria Document presents indoor NO_2 readings for instantaneous peaks, hourly peaks, hourly averages, two hour averages, and daily averages and peaks. The 1979 Criteria Document puts a range of 0.25-0.5 ppm on "usual" peak hourly readings in homes with gas stoves, while noting that levels of 1.0 ppm could occasionally occur. Unfortunately, this figure appears to include ambient levels, rather than the difference between gas and electric stove homes, ceteris paribus. Measurements by other researchers range from 0.13 to 1.5 ppm for peak readings.

Researchers agree more closely on the peak hourly readings found in homes with gas stoves: from 0.4 to 1.2 ppm (again, without correction for ambient levels). Three of the five readings tallied results based on alternative air exchange rates. Traynor and Hollowell suggest that an air exchange of 1.0 ppm/hour is "average." In that case, a reading of 0.8 ppm was observed.

Hourly average data, appearing in Melia (1978) for England and Palmes (1977) for the U.S. allow a comparison between readings in homes with natural gas and electric stoves:

1 hour averages of NO_2 (ppm)

	Gas	Electric	Difference
Melia	0.072	0.0095	0.0625
Palmes	0.0491	0.0083	0.0408

Measurement techniques in the two studies were similar, but Melia sampled four homes, while Palmes sampled 19. Thus, the Palmes study is likely to be more reliable. Note that his gas stove readings are only a bit more than one-half of Melia's peak hourly readings, while his electric stove readings are rather low relative to ambient conditions in most American cities.

The one 24-hour peak observed for gas stoves was 0.163 ppm (Lutz, 1974). A 24-hour average of 0.074 ppm was measured by one study (Hollowell, et al. 1980) which can be compared to a reading of 0.053 ppm for gas stove homes and 0.018 ppm for homes with electric stoves reported by another study (Lutz, 1974). However, the Lutz study used the discredited Jacobs-Hochheiser method to measure average concentrations of NO_2.

Twenty-four hour annual average comparisons appear in Speizer, et al.(1980), which tallied NO_2 readings (from 5 to 11 homes per city averaged over 5 cities) of 0.018 ppm for homes with gas stoves, 0.011 ppm for homes with electric stoves, and average ambient concentrations of 0.015 ppm. For four of the five cities the geometric mean of the NO_2 readings in gas stove homes was significantly different from the mean in electric stove homes at the 99 percent level. For one city, the level of significance was only 90 percent. Speizer also found 95th percentile readings for NO_2 in electric and gas homes of 0.0309 ppm and 0.0437 ppm, respectively. The average of the differences in readings over the five cities is, therefore, 0.0128 ppm.

Based on the discussion in this section, Palmes' value of 0.0408 ppm will be used as the difference between one hour average NO_2 readings in gas vs. electric stove homes for deriving dose-response functions from the gas stove studies. Based on Speizer et al.(1980), a 24-hour average difference of 0.007 ppm and a 95th percentile difference of 0.0128 ppm will be used. While this method of assessing damage functions from the gas stove studies provides interesting results, using the functions for benefits analysis is not considered prudent since the actual NO_2 concentrations in the homes of respondents are highly uncertain.

2. Dose-Response Results.

The final dose-response results are given below.

	Change in Respiratory Disease Frequency for 1 pphm change in NO_2		
	One Hour Average	95%tile of 24 hr. Average	24 Hour Average
Melia (1977)	14.7	46.9	85.7
Melia (1979a)	13.5	43.0	78.6
Speizer (1980)	4.9	15.6	28.6
Speizer (forthcoming)	1.7	5.5	10.0

III. MATERIALS DAMAGES

Only one study (Upham et al. 1976) reports a dose-response function for materials fading from NO_2. Beloin estimated, but did not report, a number of such functions. In addition, only one study reports a dose-response function for corrosive effects of NO_2 on metals (Haynie, forthcoming).

A. FABRIC FADING

In the controlled experiment of Upham et al. (1976), three fabrics used in draperies were exposed over 1,000 hours to varying concentrations of NO_2, SO_2, and O_3, at different temperatures and relative humidities, in the presence of light. The fabrics appeared to be vat dyed rather than colored with the more pollution-sensitive dispersed dyes. From an analysis of variance (not reported), NO_2 caused only the plum fabric (100% cotton duck) to fade significantly. Fitting the fading data to a fading function yielded the following result:

$$\Delta E = 30\left[1-3^{-(.75+.01H_2O+2.9\times10^{-5}NO_2.H_2O)t}\right]$$

where ΔE = amount of fading, measured by a color difference meter; 30 is the maximum amount of fading

H_2O = moisture in mg/m3 at 25°C, 1ATM

NO_2 = concentration, ug/m3

t = years of exposure

Seventy-eight percent of the variability of fading in the plum fabric is explained by this equation. Haynie then takes this equation and constructs an equation for percentage life lost (PLL) as a function of NO_2 exposure only.

With correction factors appearing only in the unpublished original version of the paper, Upham's results check out. Using these results, the change in PLL for alternative NO_2 standards is:

NO_2(PPM)	Change in PLL
0.053	
	2.44
0.06	
	3.36
0.07	
	3.25
0.08	

Thus, weakening the NO_2 standard from 0.06 to 0.07 PPM will reduce product life (to reach any given level of fading) by 3.36%.

Beloin (1972) uses multiple regression analysis to relate ambient SO_2, O_3, NO_2, temperature, and humidity to fading in 67 dye fabrics placed in light-tight containers in four cities. NO_2 in combination with other pollutants was a significant cause of fading for red and blue cellulosic acetate (disperse dye) used in apparel, blue cotton muslin used in apparel, and blue wool flannel used in apparel, rugs, and upholstery. Interestingly, Beloin did not find any draperies faded by NO_2.

Beloin's study could have contributed 5 or 6 dose-response functions if he had only reported his parameter estimates. As he did not, the study can only be used to identify the types of fabrics "at risk."

Beloin (1973) also ran (light-tight) chamber tests on 20 of the 67 fabrics in the ambient exposure study, including four of the six fabrics showing a significant NO_2 effect. This time these four fabrics showed high sensitivity to NO_2 at 0.05 ppm even in the absence of other pollutants. In addition, a blue nylon and a cotton vat-dyed material show high sensitivity to NO_2. Beloin notes that the cotton fabric may be a similar material to that used by Upham. Beloin also found several other materials fading from NO_2 in high concentrations (0.53 ppm). In general, the amount of additional fading decreased with time.

No studies were found that link fading to consumer behavior. Numerous consumer complaints of fading from gas-fired clothes dryers were made in the 1930s and 1940s, but changes in dyes and the introduction of inhibitors have largely eliminated such complaints. In the absence of studies about consumer behavior with respect to fabric fading, it is not clear that a product lifetime change of three percent resulting from a one ppm change in NO_2 concentrations (from Upham's function) would even be noticeable, particularly for fashionable apparel, where product lifetimes may be shorter than physical lifetimes because of changes in fashion.

B. FABRIC YELLOWING

In the course of this research, a DuPont official was queried about the yellowing of fabrics, primarily those made with spandex (the generic name for DuPont's Lycra). This discussion revealed that, because of DuPont's concern about the yellowing of women's undergarments, in-house research is being conducted on the problem.

C. CORROSION DAMAGE

Haynie (forthcoming) constructed dose-response functions by drawing on data from field experiments in St. Louis covering corrosive action in metals exposed to air pollutants, temperatures, and wind. He found that NO_2 exposures had a significant corrosive influence on zinc. NO_2 also was a significant cause of steel corrosion, although co-linearity between temperature and NO_2 prevented the construction of a dose-response function.

Haynie used multiple regression techniques and reported values of coefficients and standard errors. The results of one of Haynie's zinc equations is

	Independent Variable	RH	E	U SO_2	U NO_2	Constant
N=2974	Coefficient	0.1000	-5.460	-0.00150	0.00493	9.9242
R^2=0.560	Standard Deviation	0.0017	0.323	0.00056	0.00051	
F=943.7	F	3462.2	286.0	7.0	93.5	

where RH = relative humidity

$$= 100e^{-[6.32(\text{temperature-dewpoint})/(80+\text{temperature})]}$$

E = temperature factor

1000

ave. hr + 273.16
temperature

NO_2 = ave. hr concentrations (ug/m^3)

U = Deposition velocity

$$= 0.3025 (V - 0.1875 V^{0.9275})^{0.754}$$

where V = wind velocity at 30 m above ground level (m/sec)

The U variable is used because Haynie feels that pollutant flux represents exposure better than concentrations.

Haynie measured galvanic corrosion by changes in the amount of electric current measured between metal plates. The high sensitivity of this technique to environmental changes allows for a wide range of conditions to be incorporated into the data even though equipment is set up at only four sites. Indeed, Haynie had over 2,000 observations of environmental conditions and associated currents.

Haynie also selected data within a very narrow temperature range to eliminate the influence of this variable, and still found a significant NO_2 effect. Unfortunately, he used the corrosion rate instead of its log as the dependent variable, making the NO_2 coefficient not comparable to those from several other specifications.

He also presented a relationship combining independently determined values from stoicheometric reactions and the regression results. By this technique NO_2 and SO_2 combined explained only 1.3 percent of the variability in corrosion. Humidity was most important. This relationship represents Haynie's "best estimate."

$$CO = \left[0.045\ U \cdot SO_4 + 0.0314\ U \cdot NO_2 + e^{17.133-4.237E}\right] e^{-5.4(100-RH)/RH}$$

where CO is the best estimate of the corrosion rate for specific conditions of pollutants, temperature, and RH.

IV. VEGETATION DAMAGES

The Criteria Document was examined to identify candidate studies for the derivation of dose-response functions. Then, attempts were made to obtain all of these studies. Studies reviewed include: Thompson, et al. (1970), Spierings (1971), Stone and Skelly (1974), Zahn (1975), Tingey et al. (1971), and Reinhert et al. (1975). None of the studies can support the construction of dose-response functions. In this subsection, the reasons for this conclusion will be discussed.

The response of vegetation to NO_2 has been analyzed at progressively higher levels of biological organization (cellular, leaf injury, plant growth, and yield). Normal cellular metabolism may be altered, leaves may turn brown, yellow, or become spotted, growth may be stunted (or speeded), and yields may fall. A willingness to pay to avoid damages can be associated with all but the first of these effects. Assessing decreased marketable yield of fruit trees (Thompson, et al., 1970), and some vegetable crops (Spierings, 1971) requires dose-yield functions. Dose-growth functions could be used to assess damages to trees producing lumber and other types of marketable crops (e.g., asparagus).

Aesthetic damages to ornamental plants, trees, grass, etc., could possibly be estimated from dose-leaf damage functions.

Because this study is concerned only with valuing damages within certain cities, consideration of damages to agricultural crops and timber stands is irrelevant. Perhaps some vendors of trees as well as ornamental and vegetable plants might experience some effect. But such vendors are often located outside of cities, where land is less expensive. Rather, lower yields in home vegetable gardens and aesthetic damages to outdoor ornamental plants, trees, lawns, and public parks constitute the only damages for consideration.

Unfortunately, dose-response functions cannot be constructed for either aesthetics or vegetable gardens. Nowhere in the literature have aesthetic damages of this type been valued. Instead, researchers have focused primarily on valuing changes in visual range (although, even here, the effect of NO_2 on visibility cannot be separated from the effects of other pollutants). Estimates of the physical effects associated with changes in NO_2 concentrations are available, but only in relatively obscure terms, i.e., in terms of acres of area affected, degree of color change or change in the density of plant cover. Without additional information on how the public would react to such changes, this information is of questionable value.

The problem of valuing damages to lawns and parks is further complicated by the inhibiting effect of NO_2 on plant growth. Slower growth may be valuable because of reduced park and lawn maintenance costs. Such benefits could offset part or all of the aesthetic damages, assuming slower growth and leaf damage are always related.

Literature on damages to garden vegetables was also reviewed. Only a handful of studies focus on NO_2 damages to vegetable plants, and these usually focus on leaf damage rather than the economically meaningful measures of growth or yield. The studies that do focus on these responses fail to construct dose-response functions or design experiements to derive them. Spiering's (1971) study illustrates this problem. This controlled study of the effects of NO_2 on tomato plant growth and yield produced credible, if limited, results. Of relevance here, tomato yields were found to be 22 percent lower after exposure to 0.25 ppm of NO_2 for 128 days. Unfortunately, no attempt was made in this or any other experiment to assess the effect on tomato yield of a higher or lower dose for the same period of time (or any other period of time). Credible dose-response functions cannot be constructed from one point. Moreover, the yield change cannot be used directly because a continuous 0.25 ppm NO_2 concentration has not been observed in the target cities. Thus, this study and the others reviewed cannot provide estimates of damages.

One additional problem with these studies is their failure to properly account for the effect of other pollutants, particularly SO_2, on yields. Controlled studies of NO_2-SO_2 interaction convincingly point out their synergistic effect. NO_2 concentrations at or below current annual ambient standards can damage vegetation in the presence of SO_2 (at or below annual ambient standards) (Reinert, et al., 1975). However, the Criteria Document makes it clear that such pollutant interactions have not been integrated into studies of changes in the yield or growth of vegetation.

V. VALUATIONS

In this section studies of dollar damages to textiles faded by NO_2 exposure and several property value studies are reviewed.

A. TEXTILES

Haynie (1980) used a method developed by Mueller and Stickney (1970) that appears in the Ozone Criteria Document (1978) to value textile damage. However, this method does not use any known NO_2 dose-response information, and uses a ratio of preventative to direct costs pulled from a study on ozone and rubber elastomers.

Salvin (1976) estimates the cost of fading and preventative measures but does not give a date for which these costs apply and poorly documents his sources. His ad hoc approach is more acceptable than Haynie's, however. Costs are calculated by product. Acetate fabric costs are divided into use of more expensive dyes in Class A dyeings (quality dyes), costs of inhibitors in Class B dyeings (conventional dyes), costs of research and quality control, fading at the manufacturing and retail level, and reduced wear life to consumers. For cotton, costs for three common dyes (sulfur, direct, reactive) are calculated. Vat dyes are not considered because "they are not vulnerable to fading from NO_x." This statement directly contradicts Upham's (1976) findings, although Upham notes that the fabrics "appeared" to be vat dyed. This contradiction is particularly unfortunate because the only fabric dose-response function identified by this research relates to Upham's vat dyed material.

Finally, costs of fading to consumers of viscose rayon are calculated. Much of this material is used in automobiles. However, losses for yellowing of white cotton and fading of nylon carpets--"for which NO_2 effects are clearly established"--are not calculated in this paper, although yellowing costs were calculated in Salvin's 1970 paper.

For the loss of product life calculations, Salvin used the formula:

Loss = Sales x (percent of goods used in polluted areas x percent of products using sensitive dyes) x (percent yearly loss in wear life from NO_2).

Corrections are made for substitution of more expensive dyes. However, the loss of wear life numbers look like guesses.

For preventative costs, Salvin obtained direct unit cost estimates for expensive dyes and inhibitors, but also made guesses on research, quality control, and other activities.

The estimates in Table 7 are costs for the nation of increasing NO_2 from zero, or possibly "background," to "ambient" levels, not for marginal changes in ambient levels.

The discrepancy in total cost between Salvin (1976) and Barrett and Waddell (1973) who quote Salvin (1970) is caused by a lower estimate for acetate costs in the more recent report. The percentages of total costs for consumer and manufacturing losses as well as preventative measures given by Salvin (1970) and Barrett and Waddell (1973) bear no resemblance to those calculated from Salvin (1976). Salvin states that the 1976 work supersedes his earlier estimates.

B. PROPERTY VALUE STUDIES

The complexities of estimating the value of pollution damages by constructing physical dose-response functions can be avoided if responses to pollution leave their trace on markets. The housing market has received much

Table 7

Total Materials Damages From NO_2

Category	$ Millions	
Acetate		52.8
Substitution of Expensive Dyes	17.6	
Inhibitors	13.2	
Costs of Research	0.5	
Quality Control	0.5	
Fading--Manufacturing/Wholesale	1.0	
Reduced Wear Life	20.0	
Cotton--Reduced Wear		22.0
Sulfur Dye	5.0	
Direct Dye	15.0	
Reactive Dye	2.0	
Vat Dye	0	
Viscose Rayon--Reduced Wear		21.6
Total		96.4
Yellowing (from 1970 Report)		6.0
Total		100.4

attention in the attempt to value pollution damages. The idea is that people will be willing to pay more for housing in an area with good air quality than with poor air quality. These preferences should create price differentials between houses located in areas with different levels of air quality, ceteris paribus.

Harrison and Rubinfeld (1978) performed one of several studies that investigated the effect of different ambient concentrations of NO_2 on housing prices. They used 1970 census tract data from the Boston SMSA to obtain the median value of owner-occupied homes and a number of independent variables describing housing and population characteristics. Other sources were used to define other neighborhood characteristics. Data on NO_X and particulates were obtained from a computer simulation model. The authors did not explain what they meant by "NO_X" (as opposed to NO_2 or NO) or how the various nitrogen oxides were aggregated into a single concentration number.

Harrison and Rubinfeld report regressions with either a NO_X or a particulate variable, but not both. With these variables so highly correlated ($r = 0.96$) they felt that virtually no information would have been gained by using both in their regressions; either pollutant could have been used as a proxy for "air quality." In addition, when a regression with both variables was estimated the sign of NO_X reversed and became insignificant.[2]

If the collinearity problem is ignored and Harrison and Rubinfeld's "best guess" regression is used, then a one pphm increase in NO_X lowers median housing prices by $1613 (in 1970 $'s), if all other variables take on mean values. Using the housing value regression relationships to estimate a demand function for NOX reductions, Harrison and Rubinfeld find that a "household earning $11,500 per year in 1970 would have been willing to pay (WTP) $800 for a one pphm improvement when the NOX level was .03ppm, [and]... $2200 per year when the NOX level was .09 ppm." (p. 89) Of course, what Harrison and Rubinfeld actually measured was the WTP for "air quality improvements," a concept that may not be easy to relate to changes in NOX and particulates.

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[2] With both variables in the equation, their collinearity does not introduce bias to the estimated coefficients. However, their standard errors increase, which raises the possibility of wrongly accepting a null hypothesis. Further, the estimates are extremely sensitive to particular sets of sample data.

A study of the South Coast Air Basin (Brookshire, et al. 1979) presents estimates of the willingness-to-pay for improvements in air quality using a methodology similar to that used by Harrison and Rubinfeld. Here, again, collinearity between NO_2 and particulate concentrations precluded any estimate of the independent effect of either pollutant on air quality. For comparison with Harrison and Rubinfeld, Brookshire et al. find that a one pphm increase in NO_2 (as a surrogate for air quality) reduces the average sales price of a home in the South Coast Air Basin by $3,270 (in 1970 dollars). For the linear WTP equation with air quality in the 0.06-0.09 ppm range, the WTP for a one pphm improvement amounts to $2,719 per home (in 1970 dollars).

A follow-up study for San Francisco (Loehman, 1980) uses the same basic methods as Brookshire, et al., and adds ozone variables. However, in the Loehman study the NO_2 coefficient is positive and significant, a result the author attributes to the fact that NO_2 standards are "rarely exceeded" in the San Francisco area. Alternatively, it is possible that NO_2 concentrations are correlated with some housing characteristic, such as housing location in feet above sea level, which is positively associated with selling price but is omitted from the regression.

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TECHNICAL APPENDIX B
TO
CHAPTER V
OF THE
NO_2 NAAQS REGULATORY IMPACT ANALYSIS

OCTOBER 1984

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APPENDIX B

UPDATE OF NO_x CONTROL COST ESTIMATES

This Appendix provides methods and results of a number of revisions to control cost estimates in the 1982 draft Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS, referred to hereafter as the "CEA." (U.S. EPA, 1982). These revisions include derivation of new mobile and area source emission projections, review of recent ambient data, and updating of NO_x control costs for mobile and area sources, the Federal Motor Vehicle Control Program, point sources, and new source performance standards. In addition to the changes in inputs and methods, described in detail below, all costs were updated to constant March 1984 dollars.

UPDATE OF MOBILE SOURCE EMISSION FACTORS

The draft CEA used composite NO_x emission factors produced by EPA's MOBILE2 Mobile Source Emissions Model to project NEDS mobile source emission estimates from the 1978 baseline to 1985 and 1990. The MOBILE2 model was replaced by an updated MOBILE3 in mid-1984. The purpose of the following discussion is to compare the originally-used MOBILE2 results with similar emission projections from MOBILE3. In addition, projections based on a 1.5 gram/mile Federal Motor Vehicle Control Program (FMVCP) NO_x standard are added to the 1.0 and 2.0 gram/mile standards considered in the CEA.

The 1982 CEA used MOBILE2 to produce the composite emission factors in Table 1, estimating mobile source emission reductions which would occur due to the FMVCP. Two sets of factors were developed, one using default MOBILE2 parameters to estimate effects of a 1.0 gram/mile FMVCP standard for light duty vehicles (LDV) beginning in 1982, and the other using modified MOBILE2 emission parameters to simulate a 2.0 gram/mile

TABLE 1.

COMPOSITE NO_x EMISSION FACTORS FROM JUNE 1982 CEA (grams/mile)

Year	1.0 gram/mile LDV Standard	2.0 gram/mile LDV Standard
1978	4.32	4.32
1985	3.18	3.32
1990	2.21	2.47

LDV standard. These factors are composites for a typical distribution of vehicle types in 1978 including LDV, trucks and heavy duty vehicles.

The MOBILE2 default parameters which result in the above emission factors for the 1.0 gram/mile LDV standard for NO_x are a base rate of 0.75 gram/mile for 1982 and later LDV, with a deterioration rate of 0.15 gram/mile per 10,000 miles travelled. The average base rate is less than the 1.0 gram/mile LDV standard because most new cars will be well below the standard. The 1982 CEA does not indicate what parameters were used to simulate the 2.0 gram/mile LDV NO_x standard. Attempts to recreate the CEA composite factors for this standard indicate that a base rate of 1.3 or 1.4 gram/mile and deterioration rate of 0.11 to 0.13 gram/mile per 10,000 miles were apparently used. The specific 2.0 gram/mile standard parameters used in the CEA are not critical, however, since new MOBILE3 parameters for LDV, which were subject to a 2.0 gram/mile standard in 1977 through 1980, can be adapted to simulate relaxation of the LDV standard in 1982.

Using MOBILE3, the revised composite NO_x emission factors in Table 2 were generated for the default emission parameters which represent the current 1.0 gram/mile NO_x standard, and for a set of altered emission parameters which approximate a 2.0 gram/mile standard. The latter parameters, a base rate of 1.65 gram/mile and a deterioration rate of 0.09 gram/mile per 10,000 miles, were based on MOBILE3 rates for 1977-1980 model year vehicles, which were actually subject to a 2.0 gram/mile NO_x standard. In addition, a MOBILE3 run was made with an intermediate set of emission parameters, to approximate a 1.5 gram/mile NO_x standard. These MOBILE3 composite emission factors are based on a 1981 vehicle distribution and emission factors for individual vehicle types which were modified somewhat from those in MOBILE2.

TABLE 2.
COMPOSITE NO_x EMISSION FACTORS FROM MOBILE3 (grams/mile)

	LDV NO_x Standard (grams/mile)		
	1.0	1.5	2.0
Base Emission Rate	0.56	1.10	1.65
Deterioration Rate (per 10,000 miles)	0.09	0.09	0.08
Composite Emission Factor			
1978	4.86	4.86	4.86
1985	3.44	3.58	3.72
1990	2.63	2.91	3.16

Tables 3 and 4 provide detailed information on the vehicle-type-specific emission rates and the mix of vehicle miles traveled (VMT) which were used in the MOBILE2 and MOBILE3 runs described above. Attachment 1 provides more information on the difference between vehicle-specific emission rates used in the two models. These data indicate that the main reasons for differences between Tables 1 and 2 are the revision of emission factors for light duty gas trucks (LDGT) and the change in the proportions of LDGV and LDGT in the VMT mix used. The original MOBILE2 VMT mix, based on a 1978 "snapshot" of vehicle registration and mileage rates, included a significantly lower proportion of LDGT than the 1981 snapshot on which MOBILE3 is based. MOBILE3 emission factors for LDGT are significantly higher than those in MOBILE2, due to availability of additional information on emissions of LDGT in service and to the use of an assumed 1987 1.2 gram/mile NO_x

TABLE 3.
MOBILE 2 EMISSION FACTORS AND VMT MIXES

Year	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Vehicles
1.0 gm/mile NO_x Standard Emission Factors (gm/mile)								
1978	3.23	3.99	10.05	1.60	1.75	25.64	0.24	4.32
1985	2.05	2.39	10.53	1.14	1.96	25.64	0.84	3.19
1990	1.80	1.46	5.96	1.01	1.15	12.95	0.85	2.21
2.0 gm/mile NO_x Standard Emission Factors (gm/mile)								
1978	3.23	3.99	10.05	1.60	1.75	25.64	0.24	4.32
1985	2.23	2.39	10.53	1.14	1.96	25.64	0.84	3.32
1990	2.16	1.46	5.96	1.01	1.15	12.95	0.85	2.46
VMT Mix (percent of total fleet VMT)								
1978	0.785	0.130	0.042	0.001	0.000	0.033	0.009	
1985	0.750	0.125	0.042	0.036	0.005	0.033	0.009	
1990	0.693	0.119	0.042	0.092	0.012	0.033	0.009	

LDGV = Light duty gas vehicle
LDGT = Light duty gas truck
HDGV = Heavy duty gas vehicle
LDDV = Light duty diesel vehicle
LDDT = Light duty diesel truck
HDDV = Heavy duty diesel vehicle
MC = Motorcycle

TABLE 4.
MOBILE 3 EMISSION FACTORS AND VMT MIXES

Year	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC	All Vehicles
1.0 gm/mile NO_x Standard Emission Factors (gm/mile)								
1978	3.18	4.29	7.25	1.45	1.97	24.72	0.24	4.86
1985	2.00	3.43	5.56	1.39	1.65	20.70	0.84	3.44
1990	1.56	2.98	5.39	1.09	1.28	15.13	0.85	2.63
1.5 gm/mile NO_x Standard Emission Factors (gm/mile)								
1978	3.18	4.29	7.25	1.45	1.97	24.72	0.24	4.86
1985	2.22	3.43	5.56	1.39	1.65	20.70	0.84	3.58
1990	2.00	2.98	5.39	1.09	1.28	15.13	0.85	2.91
2.0 gm/mile NO_x Standard Emission Factors (gm/mile)								
1978	3.18	4.29	7.25	1.45	1.97	24.72	0.24	4.86
1985	2.44	3.43	5.56	1.39	1.65	20.70	0.84	3.72
1990	2.40	2.98	5.38	1.09	1.28	15.13	0.85	3.16
VMT Mix (percent of total fleet VMT)								
1978	0.669	0.222	0.040	0.001	0.000	0.060	0.007	
1985	0.652	0.215	0.040	0.023	0.008	0.054	0.007	
1990	0.635	0.201	0.041	0.046	0.021	0.049	0.007	

LDGV = Light duty gas vehicle
LDGT = Light duty gas truck
HDGV = Heavy duty gas vehicle
LDDV = Light duty diesel vehicle
LDDT = Light duty diesel truck
HDDV = Heavy duty diesel vehicle
MC = Motorcycle

standard for LDGT in MOBILE3 instead of the 0.9 gram/mile standard which MOBILE2 assumed to be effective in 1984. Tables 3 and 4 also indicate that 1985 and 1990 LDGV emission factors are lower in the MOBILE3 simulation of the 1.0 gram/mile standard, but higher for the 2.0 gram/mile standard.

Two important qualifications must be made with respect to the composite emission factors presented above. First, the use of 1981 data to construct the MOBILE3 VMT mix results in considerable inaccuracy in the MOBILE3 composite factor for 1978, since the relative proportions of LDGV and LDGT changed substantially between 1978 and 1981. Thus, the MOBILE2 composite emission factor for 1978 should be considered the baseline for MOBILE3 as well as MOBILE2 projection. This approach is also warranted by the fact that the NEDS mobile source emissions used as the 1978 baseline inventory are based on MOBILE2. Second, the projections for related LDGV NO_x standards in the preceding tables may be quite conservative, since it is not clear that manufacturers would actually abandon the post-1981 three-way catalyst/closed-loop control systems and go back to the open-loop/exhaust gas recirculation systems used to meet the 2.0 gram/mile NO_x standard in 1977 through 1980.

Table 5 summarizes trends in mobile source NO_x emission reductions predicted by MOBILE2 and MOBILE3, using the MOBILE2 1978 composite emission factors in Table 1 as a baseline. Table 6 shows the net changes in mobile source emission inventories represented by the trends in Table 5.

TABLE 5.
NO_x MOBILE EMISSION REDUCTION TRENDS
PREDICTED BY MOBILE2 AND MOBILE3

	Composite emission reductions over 1978 MOBILE2 baseline (%)				
	MOBILE2		MOBILE3		
NO_x FMVCP Standard (gram/mile):	1.0	2.0	1.0	1.5	2.0
1985	26	23	20	17	14
1990	49	43	39	33	27

TABLE 6.
NET CHANGES IN MOBILE SOURCE EMISSION INVENTORY
BETWEEN MOBILE2 AND MOBILE3 PROJECTIONS (%)

FMVCP NO_x Standard:	1.0 gram/mile	2.0 gram/mile
1985	+ 8.1	+ 11.7
1990	+ 19.6	+ 28.1

MOBILE AND AREA SOURCE PROJECTIONS

Control requirements for mobile and area sources in the CEA are determined by a linear rollback model, based on combined emissions for these source catagories in individual counties, recent air quality data, and target ambient standards. Thus the effect of the changes in Table 6 on overall control requirements depends on the ratio of area source to mobile source emissions. Since the CEA report does not provide this information for the specific areas in which controls may be required, a survey of NO_x emission inventories in 1982 ozone SIP data bases was undertaken. Table 7 shows that the relative magnitudes of area and mobile sources do not vary greatly among the areas of interest. Using the Los Angeles distribution (80 percent mobile, 20 percent area) as the extreme case, net changes in the overall emission inventory used in estimating non-point source control costs (mobile plus area sources) that would occur with use of MOBILE3 are shown in Table 8.

Since the CEA report does not provide details on the baseline and projected NO_x emissions inventories used in determining the need for future controls, it is not possible to directly assess the potential impact of changes shown in Table 8. However, it is possible to estimate

TABLE 7.
DISTRIBUTION OF AREA AND MOBILE SOURCE EMISSIONS IN 1982 OZONE SIP

Area	Distribution of Non-point Source NO_x Emissions (%)		Year
	Mobile	Area	
Los Angeles/South Coast	80	20	1979
Chicago	73	27	1980
Detroit	74	26	1980

TABLE 8.
NET CHANGES IN NON-POINT SOURCE EMISSION INVENTORY BETWEEN MOBILE2 AND MOBILE3

FMVCP NO_x Standard:	1.0 gram/mile	2.0 gram/mile
1985	+ 6.5	+ 9.4
1990	+ 15.7	+ 22.4

total change in the mobile/area source emission inventory as predicted by the CEA model, by using the mobile source emission trends shown in Table 5, the CEA assumption of a one percent annual growth rate for mobile and area emissions, and an assumed mobile/area source distribution. These estimates for the 1978 CEA baseline are presented in Table 9, and were obtained as follows:

$$\text{Total change} = 1 - [\,1 - 0.8\ (\text{Mobile reduction})]\ 1.01^n$$

Where: Total change = Estimated total net change in mobile/area source NO_x emissions, shown in Table 9

Mobile reduction = Composite mobile NO_x emission reduction from Table 5

0.8 = Ratio of mobile to total mobile/area source emissions (assumed)

1.01 = Annual CEA growth rate for mobile and area sources (1 percent)

n = Years from 1978 baseline.

TABLE 9.
ESTIMATED TOTAL CHANGE IN MOBILE AND AREA SOURCE NO_x EMISSIONS DUE TO FMVCP AND ONE PERCENT GROWTH RATE (%)

	MOBILE2		MOBILE3		
FMVCP NO_x Standard (gm/mile)	1.0	2.0	1.0	1.5	2.0
1978 Baseline					
1985	-15.1	-12.5	-9.9	-6.4	-4.8
1990	-31.5	-26.1	-22.5	-17.1	-11.6
Interpolated 1982 Baseline					
1985	-5.7	-4.7	-3.7	-2.4	-1.8
1990	-22.1	-18.3	-16.3	-13.1	-8.6

Thus, the "MOBILE2" columns for 1978 baseline in Table 9 provide independent estimates of the total projected change in mobile and area source emissions. The "MOBILE3" columns provide parallel projections using the new EPA mobile source emissions model. To allow re-assessment of future non-attainment based on 1982 ambient monitoring data, the baseline was shifted to 1982 by assuming that changes from 1978 to 1985 were linear. The results of this adjustment are shown in the lower part of Table 9. MOBILE3 results in a somewhat less dramatic overall reduction of mobile/area source emissions than MOBILE2 did. However, it should be noted that in all cases there is still a net emission reduction for the mobile and area emission inventory due to the dominance of the FMVCP mobile emission reductions.

AMBIENT NO_x DATA UPDATE

Table 10 presents a summary of CEA base year NO_2 values for all areas exceeding the 0.053 ppm standard, and more recent monitoring data for those areas. The base year values are the highest annual average for each area in 1976-1978, as selected specifically for use in the CEA.

The more recent data are taken from EPA air quality trends reports, and represent the highest annual average value for the SMSA. (U.S. EPA 1981, 1984). At least two areas not listed in Table 10 exceeded the standard in 1979, and values of 0.053 were recorded in several areas in 1976-1978 and in one area in 1982. As Table 10 indicates, however, only the Los Angeles-Long Beach, California, SMSA exceeded the standard in 1982.

TABLE 10.
SUMMARY OF RECENT HIGHEST ANNUAL NO_2 AVERAGES
BY SMSA (ppm)

	1976-1978[a]	1979[b]	1980[c]	1981[c]	1982[c]
Los Angeles - Long Beach, CA	0.081	0.078	0.071	0.071	0.062
Chicago, IL	0.078	0.078	0.060	0.050	0.052
Riverside - San Bernadino - Ontario, CA	0.066	0.066	0.050	0.049	0.044
Detroit, MI	0.063	0.048	0.036	0.038	0.019
Anaheim - Santa Ana - Orange Grove, CA	0.060	0.060	0.055	0.061	0.048
San Diego, CA	0.058	0.049	0.036	0.043	0.030
Philadelphia, PA	0.055	0.049	0.046	0.046	0.039
Indianapolis, IN	0.055	0.055	0.036	0.030	0.028
Denver, CO	0.054	0.051	0.050	0.047	0.039

[a] CEA base year annual average NO_2 values, the highest value for 1976-1978.

[b] Reference: U.S. EPA, 1981

[c] Reference: U.S. EPA, 1984

MOBILE AND AREA SOURCE CONTROL COST UPDATE

Table 9 indicates that no area currently attaining the NO_x standard will exceed it in 1985 or 1990 under the assumed 1.0 percent mobile/area source growth rate and 1.0, 1.5 or 2.0 gram/mile FMVCP standards. Thus, according to our hypothetical analysis, the Los Angeles-Long Beach SMSA is the only area that needs to implement a NO_x emission control program for any of the alternative NO_x standards being considered (0.053, 0.060, 0.070). Tables 11 through 13 summarize an updated control cost analysis for this area, based on previous CEA cost model estimates.

Table 11 provides the results of an analysis of ambient NO_x reductions needed to meet the 0.053 and 0.060 ppm NO_x standards under the revised 1982 baseline. The upper half of the table compares estimated CEA ambient data projections to those derived using the new Los Angeles-Long Beach high NO_x value and revised emission projections. Since the CEA used a linear rollback to project air quality, the changes in emissions from Table 9 can be used to project the available baseline ambient NO_x levels to 1985 and 1990. The bottom half of the table indicates the further emission reductions required to meet the alternative standards.

Table 12 provides available control cost estimates for maximum feasible control of mobile and area sources in the Los Angeles-Long Beach SMSA, updated to March 1984 from cost breakdowns provided by the original CEA control cost model runs. As noted, a maximum control level cost was not available for area source controls under a 1.0 gpm FMVCP in 1990, and the cost of the highest available control is presented. The data in Table 12 were used to generate the updated control costs in Table 13. These costs parallel the CEA scenarios, in which inspection and maintenance (I/M) and transportation control measures (TCM) were either assumed to be implemented first, with area source controls then applied using a least-cost algorithm, or in which I/M and TCMs were not used at all. Area source costs were estimated by assuming a linear relationship between cost and ambient NO_x reduction, based on the values in Table 12. This probably results in some

TABLE 11.
AMBIENT AIR QUALITY ESTIMATES FOR COST UPDATE

	CEA (1978 Baseline) Analysis		1982 Baseline Update		
Los Angeles-Long Beach SMSA High Value, ppm	0.081		0.062		
FMVCP Standard, gm/mile	1.0	2.0	1.0	1.5	2.0
Change from Baseline (from Table 9), percent					
1985	-15.1	-12.5	-3.7	-2.4	-1.8
1990	-31.5	-25.1	-16.3	-13.1	-8.6
Projected High Values					
1985	0.069	0.071	0.060	0.061	0.061
1990	0.055	0.060	0.052	0.053	0.057

Ambient Reductions Needed for Updated Costs (1982 Baseline), percent	FMVCP Standard		
0.053 ppm NO_x NAAQS	1.0	1.5	2.0
1985	11.7	13.1	13.1
1990	0	0	7.0
0.060 ppm NO_x NAAQS			
1985	0	1.6	1.6
1990	0	0	0

overestimation of costs for cases not requiring the maximum available emission reduction, relative to the original least-cost solutions in the CEA. Since there were no CEA costs for the 1.5 gpm FMVCP, the 2.0 gpm costs in Table 12 were used. This should result in a further overestimate in this case, since the higher FMVCP costs result in more expensive ambient level reductions.

FMVCP COST UPDATE

Table 14 contains updated costs for the Federal Motor Vehicle Control Program (FMVCP). These costs were updated from costs contained in Chapter 6 of the CEA. Costs and credits for FMVCP-related changes in fuel economy were eliminated from the original CEA estimates based on guidance from EPA-Ann Arbor. (Hellman, 1984). This is because potential changes in fuel economy due to FMVCP are impossible to isolate from changes due to regulations specifically controlling fuel economy.

To assess potential cost impacts of instituting a 1.5 gpm NO_x FMVCP in 1984, CEA cost estimates were modified by assuming that all light duty vehicles would use oxidation catalyst-based control systems rather than the three-way catalyst systems assumed in the CEA. This is a highly conservative assumption, since it is not likely that the entire new-car fleet will revert to oxidation catalysts. According to recent EPA estimates (Gray, 1983), the NO_x-related capital cost for an oxidation-catalyst open-loop control system is about one-quarter of the capital cost of the dominant three-way catalyst systems in use in 1983 vehicles. The methodology in CEA Section 6.2.1 was applied to estimate the cost of this assumed control technology for a 1.5 gpm NO_x standard beginning in 1985. The CEA analysis for a 2.0 gpm standard was also revised to begin the relaxed standard in 1985 instead of 1981. In both cases, the technology already in place from 1981 through 1984 dominates the annualized costs shown in Table 14. Similarly, operating and maintenance costs shown in Table 14 for the two relaxed standards consist entirely of costs for the 1981-1984 three-way catalyst technology, since the 1.5 and 2.0 gpm technologies do not involve additional O & M costs.

TABLE 12.
MAXIMUM CEA CONTROLS POSSIBLE IN LOS ANGELES-LONG BEACH AREA

	Annualized Cost (millions of March 1984 dollars)	Ambient Reduction (percent)[a]
1985		
1.0 gpm FMVCP		
I/M	25.3	4.3
TCM	---	1.4
Area sources	176.5	11.5
2.0 gpm FMVCP		
I/M	25.3	5.6
TCM	---	1.4
Area sources	176.5	9.8
1990		
1.0 gpm FMVCP		
I/M	10.2	8.6
TCM	---	Negligible
Area sources[b]	105.1	10.3
2.0 gpm FMVCP		
I/M	10.2	8.1
TCM	---	1.6
Area sources	190.9	12.9

[a] Ambient reduction percentages subject to uncertain accuracy due to rounding of predicted ambient concentrations by CEA cost model.

[b] This entry represents the highest control level required by CEA scenarios; however, maximum feasible control was never required in this case.

TABLE 13.
ESTIMATED ANNUALIZED COST OF ATTAINING ALTERNATIVE NO_2 NAAQS[a]
(millions of March 1984 dollars)

FMVCP Standard:	1.0 gm/mile	1.5 gm/mile[b]	2.0 gm/mile
I/M, TCM Used First			
0.053 ppm NO_x NAAQS			
1985	117.2	135.1	135.1
1990	0	0	10.2
0.060 ppm NO_x NAAQS			
1985	0	25.3	25.3
1990	0	0	0
I/M, TCM Not Used			
0.053 ppm NO_x NAAQS			
1985	176.5	176.5[c]	176.5[c]
1990	0	0	103.8
0.060 ppm NO_x NAAQS			
1985	0	28.8	28.8
1990	0	0	0

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[a] Zero costs indicate that no controls in addition to FMVCP and NSPS are required to attain the NAAQS. A 0.070 ppm NAAQS would not be exceeded under any CEA scenario.

[b] Based on Table 12 costs for a 2.0 gpm FMVCP.

[c] NAAQS not attained with maximum available controls.

TABLE 14.
TOTAL ANNUALIZED COST OF THE FEDERAL MOTOR VEHICLE CONTROL PROGRAM
(Millions of March 1984 Dollars)

	FMVCP:					
	1.0 gpm		1.5 gpm		2.0 gpm	
Vehicle type	1985	1990	1985	1990	1985	1990
Light-duty vehicles						
Hardware	1,086	2,003	915	944	884	735
O&M	399	790	308	225	308	225
Unleaded fuel	352	747	352	747	352	747
Subtotal	1,837	3,540	1,575	1,916	1,544	1,707
Light-duty trucks	67	535	67	535	67	535
Heavy-duty vehicles	2	398	2	398	2	398
TOTAL	1,906	4,473	1,644	2,849	1,613	2,640

POINT SOURCE CONTROL COSTS

Table 15 contains updated annualized point source control cost estimates for 1985 and 1990, taken from Tables 5-1 and 5-2 of the CEA. There are no point source controls required for a 0.070 ppm NO_x standard.

NEW SOURCE PERFORMANCE STANDARD (NSPS) COSTS

Based on the mid-point of 1990 NSPS annualized costs presented in Chapter 6 of the CEA, NO_x NSPS control costs are updated to $110 million in 1985 and $250 million in 1990.

TABLE 15.
POINT SOURCE CONTROL COST ESTIMATES FOR ALTERNATIVE NO_2 STANDARDS

Year	NO_2 Standard	Number of Sources Controlled	Annualized Cost (millions of March 1984 $)	Number of Nonattainment Plants
1985	0.053	172	11.67	1
	0.060	16	0.76	0
1990	0.053	104	2.01	0
	0.060	10	0.10	0

THE RECENT NOX (AND PARTICULATE) EMISSION STANDARDS PROPOSAL

EPA's Office of Mobile Sources recently proposed to reduce future NOx emissions from light duty trucks and heavy duty engines (49 FR 40258). The changes proposed are summmarized in Table 16. They do not apply to motor vehicles sold in California because that State has its own vehicular control program.

The newly proposed standards are more stringent than current FMVCP standards, thus fewer emissions are to be expected from each regulated vehicle on a per mile basis. However, as will be described below, these changes do not impact upon most of the cost or non-attainment results presented in this report.

Since the proposed changes in motor vehicle emission standards do not take effect until the 1987 model year (beginning in late 1986) at the earliest, the changes of course do not impact upon 1985 costs presented in Tables 5.1-5.3 and in the updated cost tables of this Appendix (Tables 13-14). Since the new FMVCP standards do not affect emissions in the one NO_2 non-attainment area that we have identified--Los Angeles--the changes do not affect the "additional mobile/area" cost estimates contained in Tables 5.4-5.6 or in the updated Table 12 of this Appendix. Thus, the only impact of the proposed changes in NOx emission standards is to alter FMVCP costs for 1990.

Table 14 of this Appendix presents data relating to FMVCP costs for various vehicle types. Estimated costs presented in the Cost and Economic Assessment (EPA, 1982) for the "light-duty trucks" and "heavy-duty vehicles," the two vehicle types most closely corresponding to those affected by the proposed emission standard changes, are $933 million annualized 1990

TABLE 16.
CHANGES IN MOTOR VEHICULAR NOx EMISSION STANDARD PROPOSED IN 49 FR 40258

	Light Duty Trucks ≤6,000 GVW (gpm)	Light Duty Trucks >6,000 GVW (gpm)	Heavy Duty Engines (Gasoline and Diesel) (g/BHP-hr)
Current FMVCP			
1985 and on MY[a]	2.3	2.3	10.7
Proposal FMVCP			
1987-1989 MY	1.2	1.7	6.0
1989 and on MY	1.2	1.7	4.0

Abbreviations:

NOx = nitrogen oxides
GVW = gross vehicle weight
gpm = grams per mile
g/BHP-hr = grams per brake horsepower-hour
FMVCP = Federal Motor Vehicle Control Program
MY = model year

Note: a. The current FMVCP emission standards do not distinguish between the two weight classes of light duty trucks; thus both classes have the same standard.

costs in 1984 dollars. (This is approximately $527 million in present value terms.) These costs do not vary by the FMVCP standards shown in Table 14, since those standards apply only to light-duty vehicles.

The proposed NOx emission changes would significantly increase FMVCP costs presented in Table 14. The increase in costs is due to the following factors (Office of Mobile Sources, n.d.):

1. additional fixed or pre-production, costs assocaited with the research development, and testing of new control technology to meet the tighter proposed standards. (These costs include one-time certification activities that must occur prior to the manufacture of control equipment.
2. variable costs associated with the manufacture and installation of new control technology.
3. operating costs associated with use of the equipment. These costs generally are comprised of fuel penalties and additional maintenance. (However, it may be possible to obtain negative costs, i.e., a savings, due to these items; see below.)
4. a 10% "contingency factor" that is added to Mobile Source's cost estmates to account for uncertainty in the technological and monetary assumptions used in their analysis.

While the Mobile Source Draft RIA presents cost (and economic) information related to both NOx and particulate control, we are concerned here only with NOx control cost estimates. In addition, for the reasons stated above, we are concerned only with Mobile Sources' 1990 estimates. Said estimates appear in Table 17. A brief discussion of the data appearing in the Table is in order.

TABLE 17
ADDITIONAL 1990 FMVCP COSTS ASSOCIATED WITH THE RECENTLY PROPOSED LDT AND HDE EMISSION STANDARDS[1]

Vehicle Class	Item	1990 Costs ($$10^6$)	Present Value of the 1990 Costs[2] (10^6)
LDT	Fixed and variable costs	254	144
	Fuel penalty/savings[3]	±856/1%	±484/1%
HDGE	Fixed and variable costs	2	1
HDDE	Fixed and variable costs	103	58
	Maintenance costs	4	2
	Fuel penalty[4]	0-452	0-255

Source: Office of Mobile Sources (n.d.)

Abbreviations:
FMVCP = Federal motor vehicle control program
LDT = Light duty trucks (gasoline and diesel fueled)
HDE = Heavy duty engines (gasoline and diesel fueled)
HDGE = Heavy duty gasoline engines
HDDE = Heavy duty diesel engines

Notes:

[1] Proposed in 49 FR 40258, October 15, 1984. Costs appearing in this table should be added to those appearing in Table 14 of this RIA. All costs are in 1984 dollars except where otherwise noted.

[2] Discounted back to 1984 using a 10% interest rate or discount factor.

[3] In 1990 discounted dollars, over the lifetime of the vehicle, assumed to be 11 years.

[4] In 1990 discounted dollars for the time period 1990-1992.

The increase in LDT costs due to control technology development and testing (the "fixed" costs) and manufacture and installation ("variable" costs) are $254 million in 1990. In addition, Mobile Sources states that "it is reasonable to expect that some small increase could occur in the fuel econoy of some LDGTs and some small decrease could occur in the fuel economy of some LDDTs" (p. 3-22). Because it was difficult to estimate (1) the number of trucks that would save fuel, or use more fuel, and (2) the amount of fuel saved per vehicle (due to unknown sales figures and unknown vehicle miles traveled per vehicle), Mobile Sources presented a "contingent" fuel savings estimate for the LDT class of vehicles. Their estimate is $856 million per one percent change in fuel economy over the lifetime of the vehicle class (assumed to be 11 years). This figure is in 1987 discounted dollars, so it is not comparable to the fixed and variable costs estimate for LDTs. Thus, the 1990 LDT costs shown in Table 17 could be higher or lower than $254 million by some undefined amount due to changes in fuel consumption associated with NOx control technology needed to achieve the 1.2/1.7 grams per mile emission standards for LDTs.

The additional 1990 FMVCP costs for HDGEs are modest: only $2 million. According to Mobile Sources, there are no additional maintenance or fuel impacts associated with the 4.0 g/BHP-hour emission control technology for heavy duty gasoline engines.

For heavy duty diesel engines, however, the proposed standard will have a significant technological (and cost) impact. Fixed and variable costs are estimated by Mobile Sources to be $103 million in 1990 ($58 million PV). To this is added (1) a maintenance expenditure of approximately $4 million (due to extra maintenance of the NOx aftercooling system technology),* and (2) a fuel penalty cost of between $0-452 million for 1990.

The wide range of the fuel penalty cost estimate is due to uncertainty in the percentge fuel penalty associated with NOx control equipment. Mobile Sources estimates that it could be between 0% and 2%, but only in the short-term (2 years or so), because engine and vehicle improvements will be made that will overcome any fuel penlty associated with the initial NOx control equipment.

As with the LDT fuel penalty/savings estimte contained in Table 17, HDDE fuel penalty costs are not comparable with the other two cost categories for the HDDE class of vehicles due to the form in which the fuel penalty costs are presented in Office of Mobile Sources (n.d.).

In summary, the proposed changs in NOx emission standards contained in 49 FR 40258 would increase FMVCP costs appearing in this report by the amounts shown in Table 17. However, as was explained above, the fuel penalty and savings estimates contained in Table 17 cannot be used directly due to the matter in which those estimates were calculated or presented in the Draft Mobile Source RIA.

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*Mobile Sources estimates that there is an overall maintenance savings associated with HDDE control technology as a unit, but stated that the NOx portion of the technology involved additional maintenance work (as distinguished from the particulate portion, which saved money in equipment repair).

It should be noted that the methodologies used to estimate needed future emission reductions differ in the Draft RIA for NOx emission standards (Office of Mobile Sources, n.d.) and this Draft RIA for alternative NO_2 NAAQS. There are two important differences: the base year air quality data used to obtain a design value and the annual growth rate in mobile source vehicle miles traveled.

Mobile Sources' RIA used 1980-81 air quality data whereas OAQPS used 1981-1983 air quality data. This difference is significant since NO_2 annual averages are trending downwards more rapidly than the NOx emission inventory changes. Thus, using an older air quality data base results in relatively high design values vis-a-vis the emissions base, leading to more control hypothetically being needed to attain and maintain a given NAAQS level.

For growth in vehicle miles traveled, Mobile Sources used vehicle class specific factors for light duty vehicles, heavy duty vehicles, light duty trucks, and so forth. These factors vary between -0.3% per year for heavy duty gas vehicles to +4.7% per year for light duty trucks. The approximate average for all motor vehicles is on the order of 1.8-2.0% per year. This is considerably higher than the NO_2 NAAQS analysis's use of 1.0% per year for all motor vehicles as a class.* The 80-100% increase in emissions growth rate directly results in the large number of NOx non-attainment areas that the Mobile Sources' Draft RIA predicts will occur in 1995. (OAQPS did not carry its analysis out to 1995. It stopped in 1990, because of the short planning horizon associated with the five-year review cycle of all national ambient standards. For the sake of comparison, Mobile Sources predicts 2 NOx non-attainment ares in 1990 whereas we predict none.)

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*Due to increasing vehicle miles traveled, or VMT, in an area. This rate varied between -0.5% and +1.5% per year for the 1979-1982 time period. (Motor Vehicle Manufacturer's Association, 1983.).

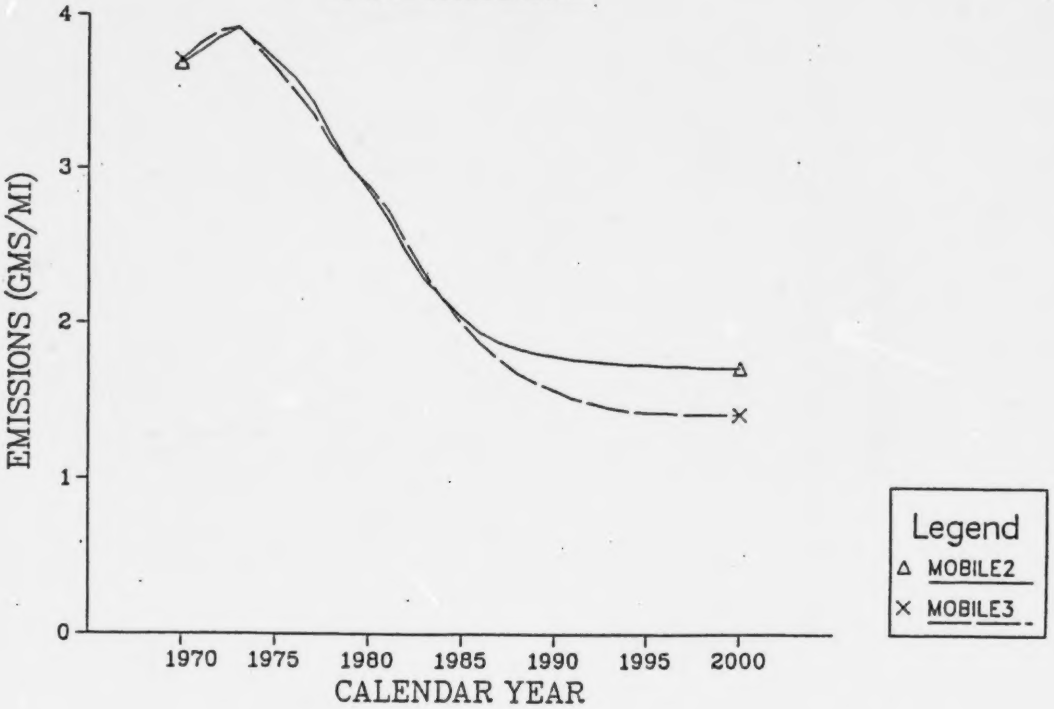
There are other analytic and procedural differences between the two regulatory analyses, but none as important as those mentioned above. For a complete understanding of the analyses, see Office of Mobile Sources (n.d.) and reference 52 (p. 75).

ATTACHMENT 1:

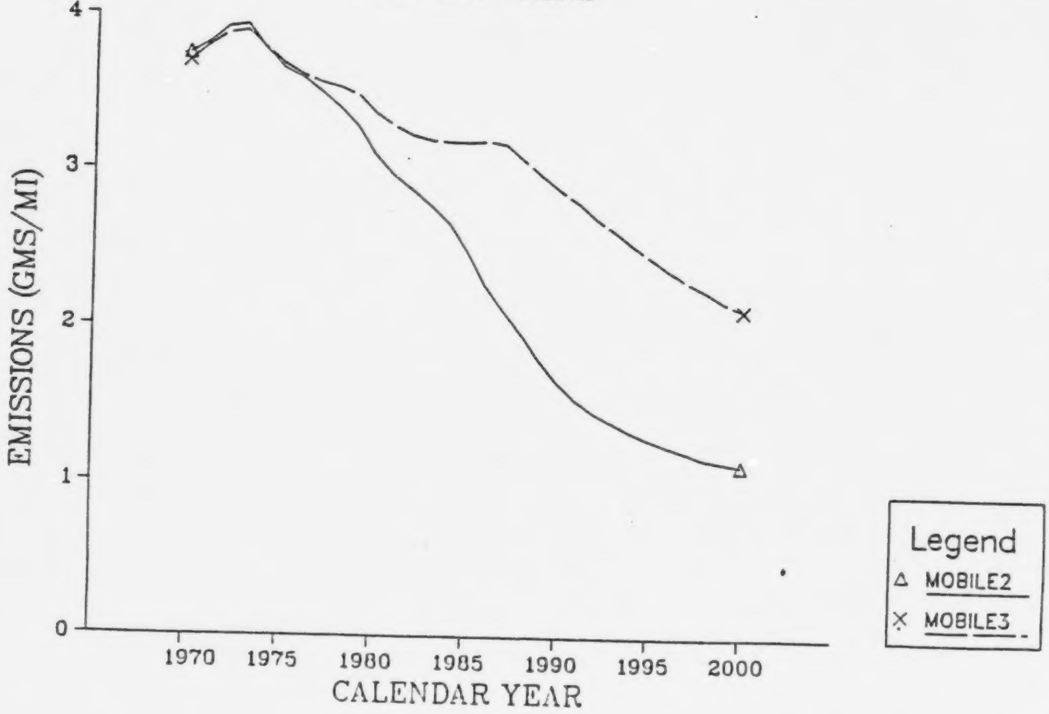
COMPARISON OF MOBILE 2 AND MOBILE 3 EMISSION FACTORS BY VEHICLE TYPE

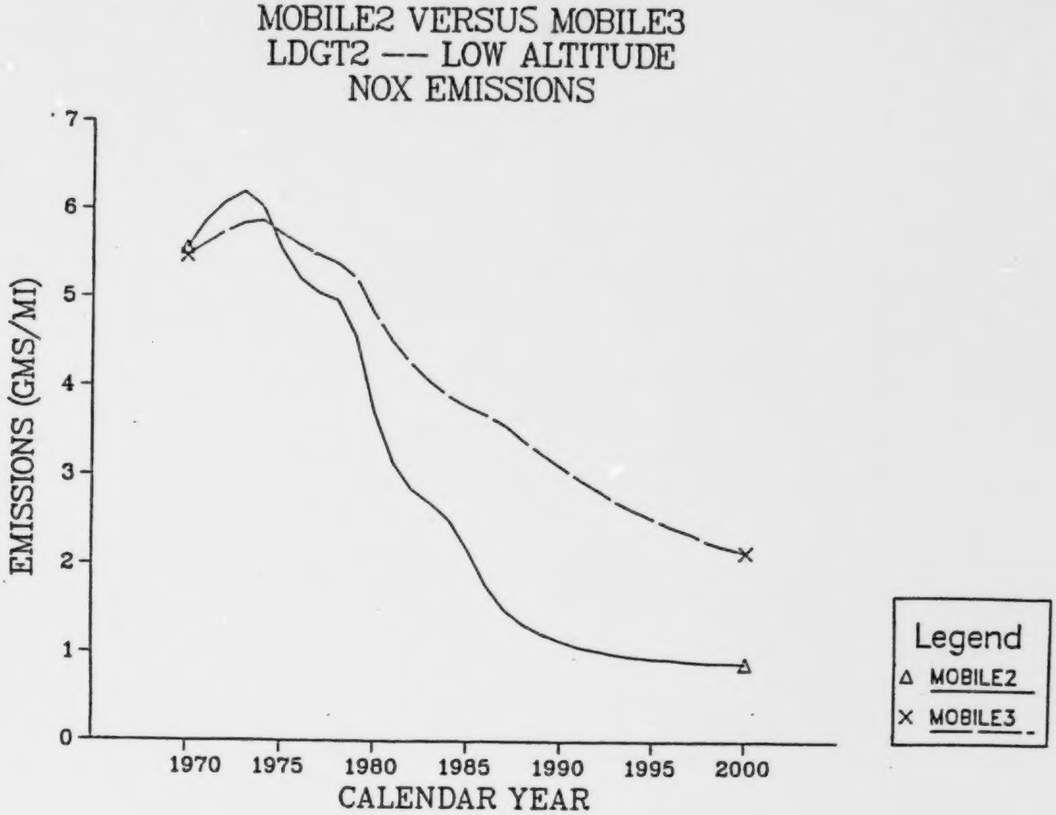
The following graphs were prepared by EPA-Ann Arbor staff for MOBILE 3 workshops. They are based on MOBILE 3 default conditions and typical data values.

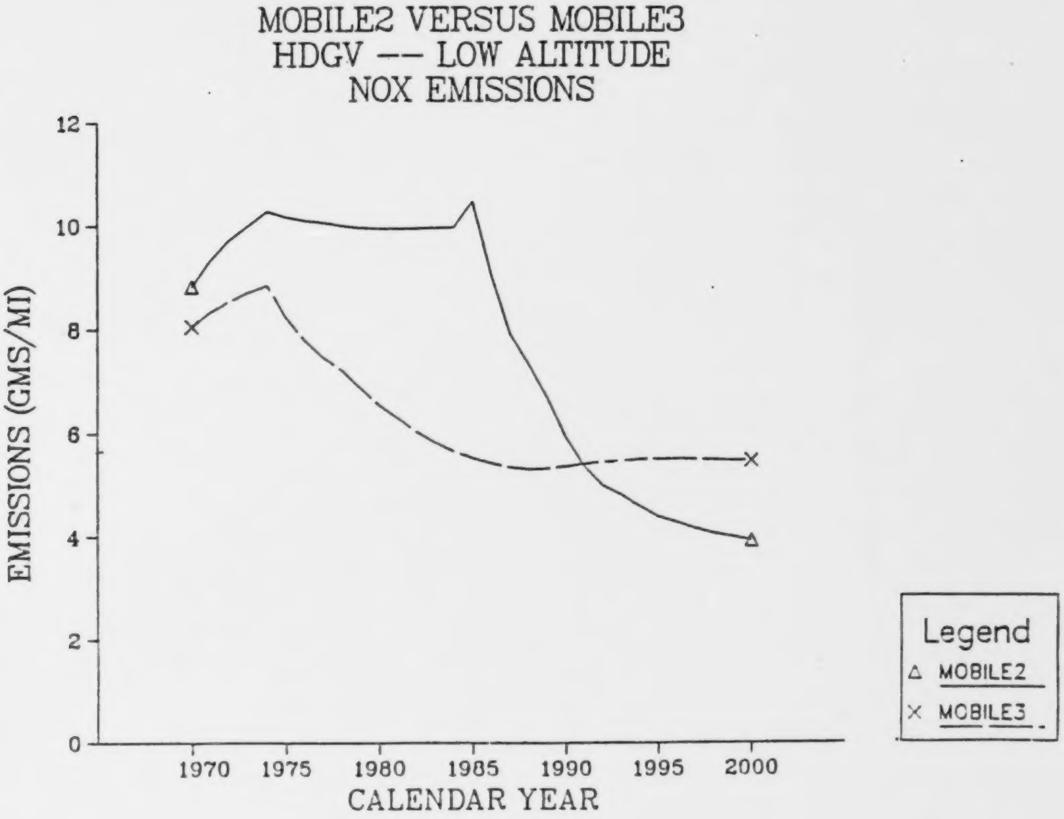
MOBILE2 VERSUS MOBILE3
LDGV -- LOW ALTITUDE
NOX EMISSIONS



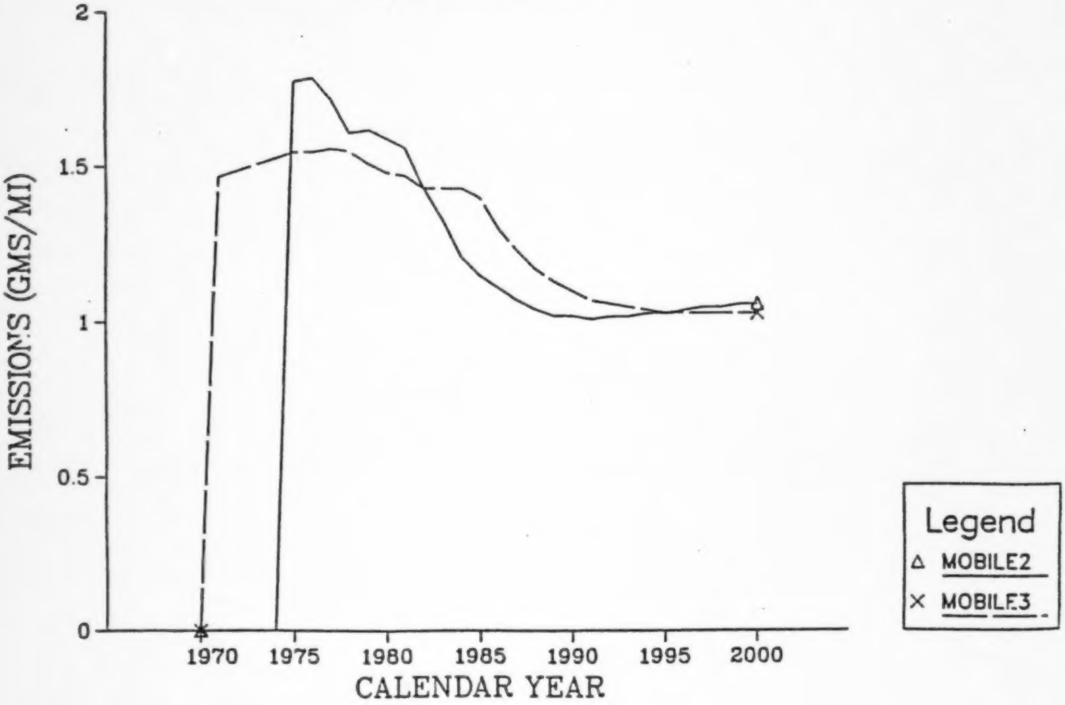
MOBILE2 VERSUS MOBILE3
LDGT1 -- LOW ALTITUDE
NOX EMISSIONS



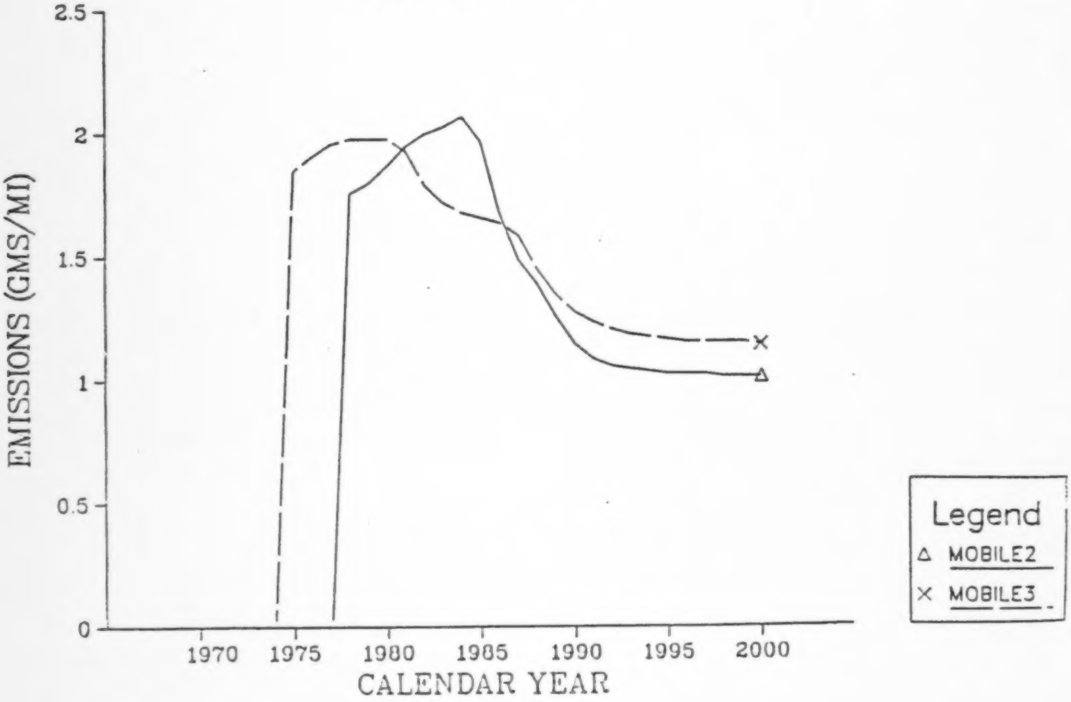

MOBILE2 VERSUS MOBILE3
LDGT2 -- LOW ALTITUDE
NOX EMISSIONS
EMISSIONS (GMS/MI)
0
1
2
3
4
5
6
7
1970
1975
1980
1985
1990
1995
2000
CALENDAR YEAR
Legend
△ MOBILE2
× MOBILE3

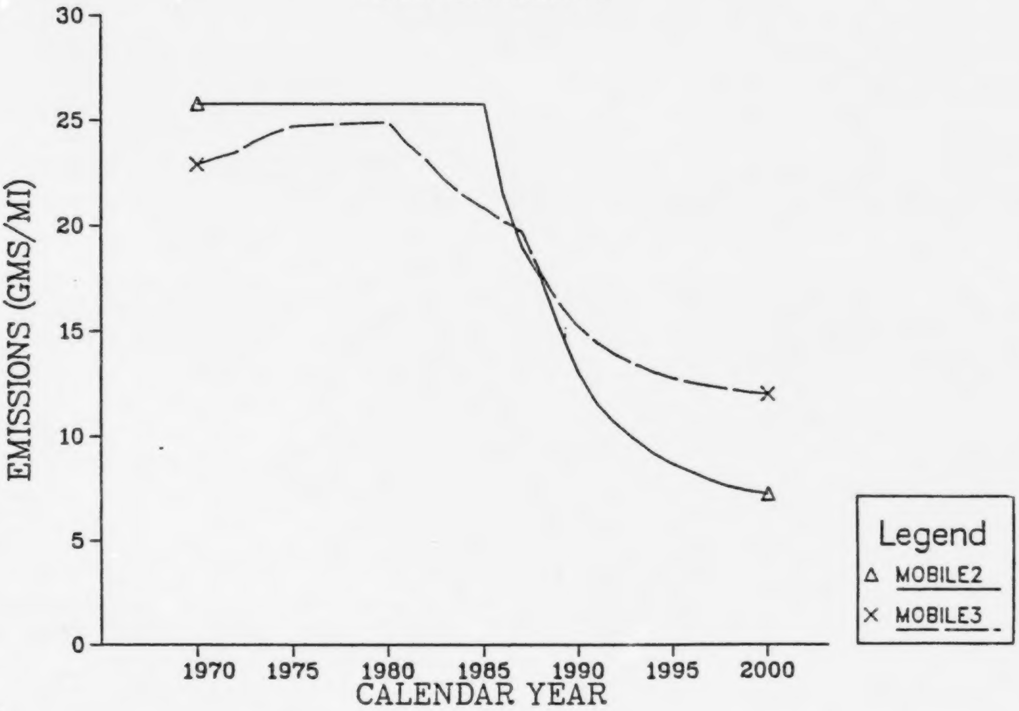

MOBILE2 VERSUS MOBILE3
HDGV -- LOW ALTITUDE
NOX EMISSIONS
EMISSIONS (GMS/MI)
0
2
4
6
8
10
12
1970
1975
1980
1985
1990
1995
2000
CALENDAR YEAR
Legend
△ MOBILE2
× MOBILE3

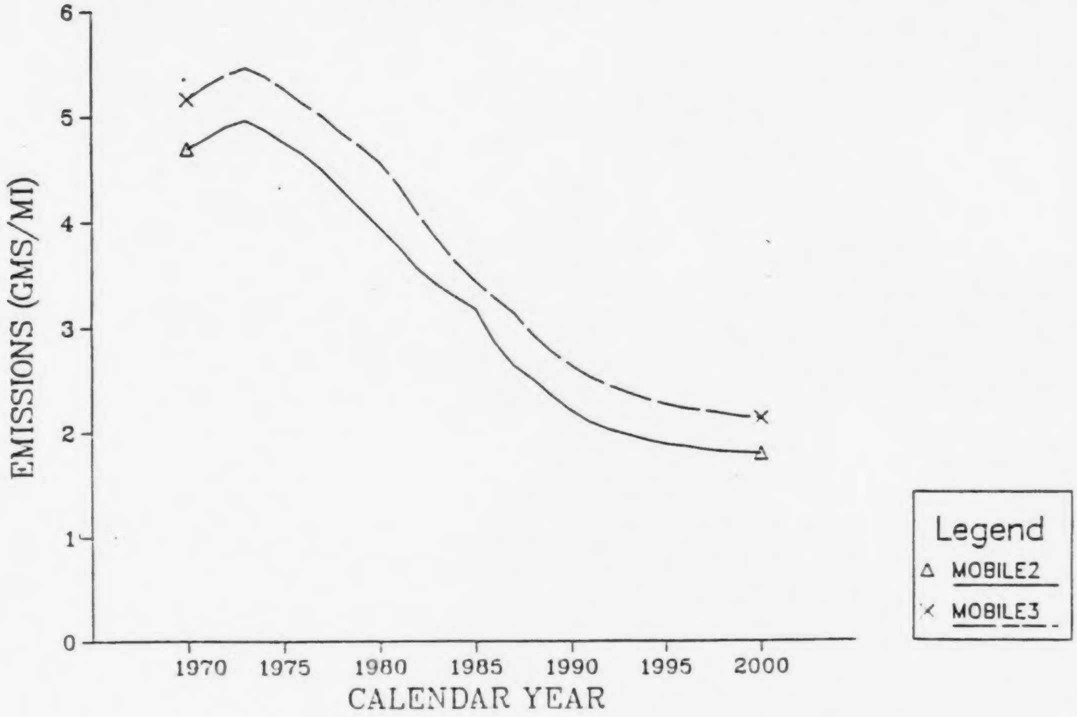
MOBILE2 VERSUS MOBILE3
LDDV -- LOW ALTITUDE
NOX EMISSIONS



MOBILE2 VERSUS MOBILE3
LDDT -- LOW ALTITUDE
NOX EMISSIONS




MOBILE2 VERSUS MOBILE3
HDDV — LOW ALTITUDE
NOX EMISSIONS


MOBILE2 VERSUS MOBILE3
ALL MOBILE SOURCES COMBINED — LOW ALTITUDE
NOX EMISSIONS

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TECHNICAL APPENDIX C
OF THE
NO_2 NAAQS REGULATORY IMPACT ANALYSIS

OCTOBER 1984

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APPENDIX C

NO_x CONTROL TECHNOLOGY FOR STATIONARY SOURCES

The purpose of this Appendix is to review stationary source NO_x control technologies relevant to the NO_2 NAAQS, and to provide background information on control technologies for combustion processes used in the Cost and Economic Assessment of Regulatory Alternatives for NO_2 NAAQS (CEA).[1] The CEA estimates of NO_x control costs for point and area stationary sources were based on selection of the least-cost combination of controls which would allow attainment of a given NO_2 standard. Controls were chosen from lists of the types of control technologies applicable to each source type (CEA Tables 4-6 and 4-15). These controls include all known techniques believed to be suitable for retrofit application to the sources of concern over the time frame of the CEA analysis (i.e. through 1990).

For combustion sources, which account for over 90 percent of all stationary source NO_x emissions, NO_x controls fall into two categories: those controls which modify the combustion process to suppress NO_x formation; and those controls which remove NO_x from the flue gas after combustion has been completed. Of the combustion controls used in the CEA, low excess air, staged combustion, flue gas recirculation, reduced combustion intensity, and low NO_x burners are combustion modification techniques, while selective catalytic reduction, and ammonia injection (selective non-catalytic reduction) are flue gas treatments. Detailed background information on each of these controls is presented later in this Appendix. The CEA distinguishes between currently "commercially demonstrated" controls, which are considered available in 1985, and "undemonstrated" controls, which are applied only in estimating costs for 1990. The latter category consists of the two flue gas treatment methods, ammonia injection and selective catalytic reduction, which have been used in the U.S. only on a limited pilot or demonstration project basis. Recent review of the status of NO_x control technology development by EPA groups cognizant in the field indicates that the control availability and cost information used in the CEA remains valid.[2,3]

There are a number of potential NO_x control techniques which were not applied in the CEA analysis because their development is not expected to result in significant control technology shifts by 1990. These include reburning (fuel staging), precombustors, and stoker gas recirculation. Many specific applications of these principles are in testing stages, but only a few are commercially available on a very limited basis, or for control of pollutants other than NO_x. Reburning is available only as a part of one low-NO_x burner package. Stoker gas recirculation is being used on several stoker boilers for particulate control, but has restricted applicability due to the small number of stoker boilers.[2] Other potential NO_x control approaches which are actually modifications to basic combustion technologies, such as fluidized bed combustion and combined cycle gasifiers, are not amenable to retrofit situations and thus are not considered for control of existing NO_x sources in the CEA.

The CEA controls discussed above apply mainly to industrial and utility boilers, but some also apply to industrial process furnaces and reciprocating internal combustion engines. Fine-tuning and changing air/fuel ratio or increasing stack height are additional controls available for reciprocating internal combustion engines. The other two CEA point source categories with available controls are stationary gas turbines (water injection) and nitric acid plants (chilled absorption). NO_x controls are not available for process heaters or catalytic crackers in the petroleum industry, glass melting furnaces, process-gas-fueled blast furnaces, and coke ovens.

LOW EXCESS AIR COMBUSTION (LEA)

Reducing the amount of excess air supplied for combustion has been shown to be an effective method for reducing NO_x emissions from utility and industrial boilers, residential and commercial furnaces, warm air furnaces, and process furnaces. In this technique, the combustion air is reduced to the minimum amount required for complete combustion, while maintaining acceptable furnace cleanliness, (ie. no fouling or slagging) and steam temperature. Reducing the amount of excess air also reduces the amount of both thermal and fuel NO_x since there is less O_2 available in the flame zone. Boiler efficiency also is improved because the reduced airflow also lowers the quantity of the gas released.[4]

Since boilers are not perfect combustion devices, excess air is always supplied to ensure complete combustion. This includes complete reaction of the fuel (HC) and oxidation of most of the resulting CO to CO_2. Too much excess air causes increased NO_x formation due to an oxygen-rich combustion zone and reduced boiler efficiency due to increased dry gas loss up the stack. Too little excess air causes some fuel to leave the combustion zone unreacted and a large amount of CO to exit unoxidized. Both sets of conditions are unacceptable from both a safety and efficiency standpoint.[4]

Optimum conditions would require just enough excess air to avoid smoking (caused by incomplete combustion), have zero unburned hydrocarbons, small CO emissions (less than 100 ppm), and handle any process variations such as low load operation, nonuniformity of air/fuel ratio, fuel and air control lags during load swings, and fuel variations. Low excess air is a simple, feasible, and effective technique to control NO_x emissions from utility and industrial boilers and is presently considered a routine operating procedure in these combustion processes. Most sources will require additional control methods, in addition to LEA to reduce NO_x levels to within statutory limits.[5] Effectiveness of this technique may range from 5-25 percent NO_x reduction depending on the initial level of excess air used.

STAGED COMBUSTION

Staged or off-stoichiometric combustion (OSC) involves initial combustion in a fuel-rich zone followed by secondary combustion at lower temperatures in a fuel-lean zone. The fuel-rich zone is essentially an oxygen-deficient zone which inhibits the formation of thermal NO_x and also reduces fuel NO_x formation by providing a time span for a portion of the fuel bound nitrogen to be reduced to N_2. If heat is transferred to the walls prior to secondary air addition and the completion of combustion, then the temperatures in the fuel-lean secondary zone will be lower. Lower temperatures inhibit thermal NO_x formation.[5]

The most commonly used staged combustion techniques are biased burner firing (BBF), burners-out-of-service (BOOS), and overfire air injection (OFA). The following gives a brief discussion of each technique.

Biased Burner Firing (BBF)

Biased burner firing is achieved by creating fuel-rich and fuel-lean regions in the primary combustion zone. Typically, this is done by firing the lower rows of burners more fuel-rich than the upper rows of burners. The additional air required for complete combustion enters through the upper rows of burners which fire a fuel-lean mixture. This technique allows all of the burners to remain in operation.[5]

Burners Out of Service (BOOS)

The burners-out-of-service technique is the extreme of biasing in that fuel flow is terminated at individual burners or rows of burners while maintaining air flow and redistributing to the remaining burners in service. Thus, fuel-rich conditions are created at the in-service burners while the remaining air required for combustion is introduced through the out-of-service burners. In some cases BOOS is not feasible because boiler load is decreased somewhat. This load reduction may occur because burners may be unable to handle increased fuel flow and also because some burners have been shut down.[4]

Both BBF and BOOS are applicable to all fuels and are particularly attractive as control methods for existing units, since few, if any, equipment modifications are required. However, accurate flue gas monitoring equipment and increased operator monitoring of furnace conditions are required with these combustion modifications. Monitoring flue gas, excess air, and CO will help to avoid boiler efficiency reduction through flue gas heat and unburned combustible losses and to prevent unsafe operating conditions caused by incomplete combustion.[6]

The most effective BBF or BOOS burner configuration for a particular unit is determined through field tests, although for BOOS, the out-of-service burners are typically located in the upper portions of the furnace.[6] Emissions tests for BOOS firing on utility boilers have indicated average NO_x reductions of 31 to 37 percent for coal, oil, and natural gas firing compared to earlier baseline levels.[6]

Overfire Air Injection (OFA)

The overfire air technique involves operating the burners at near stoichiometric conditions or fuel-rich with the remaining combustion air being supplied through overfire air ports located above the rows of burners or through an idle top row of burners.

Potential limitations of this technique include:

- Furnace tube wasteage due to local reducing conditions when firing coal or high sulfur oil
- Tendency for slag accumulation in the furnace
- Additional excess air may be required to ensure complete combustion resulting in a decrease in boiler efficiency.

However, these potential problems may be overcome with proper implementation of staged combustion.[4]

The major drawback with OFA is that additional duct work, furnace penetration, and extra fan capacity may be required. Thus, OFA is more attractive in original designs than in retrofit applications. In addition, there may be physical obstructions outside of the boiler setting making installation more costly. There may also be insufficient height between the top row of burners and the furnace exit to permit the installation of overfire air ports or to allow sufficient residence time for the completion of combustion.[4]

Since staged combustion techniques serve to delay or prolong the combustion process, furnace size (volume and wall surface) must necessarily be large in order to ensure complete combustion. Thus, overfire air is more easily implemented without large efficiency or cost penalties on large units than on small ones. Staged combustion techniques are typically applied to utility size boilers.[6]

Some emissions tests of OFA on utility boilers have reduced NO_x emissions 25 to 60 percent for coal, oil, and natural gas firing compared to earlier baseline levels.[6]

FLUE GAS RECIRCULATION (FGR)

Flue gas recirculation consists of extraction of a portion of flue gas from the exhaust stream and subsequent re-introduction into the furnace. The recirculated flue gas acts as a diluent in the primary combustion zone to reduce peak temperatures and lower oxygen concentration. Since the bulk of NO_x emissions from gas and most oil-fuel firing are thermal NO_x, FGR is very effective on these fuel types. For a fuel oil with high nitrogen content and coal combustion, FGR is less effective due to the large contribution of fuel NO_x to the NO_x emissions.[5] However, it can be used to reduce O_2 level in primary combustion air and thus reduce NO_x from coal-fired systems.

FGR is more attractive for new designs than as a retrofit application. This is because a retrofit requires a fan, flues, dampers, controls and possibly extra fan capacity. In addition, the FGR system itself may require a substantial maintenance program due to the high temperature environment and potential erosion from entrained ash.[6]

As a new design feature, the furnace and convective surfaces can be sized for the increase in mass flow and change in furnace temperatures. In contrast, in retrofit applications the increased mass flow increases turbulence and mixing in the burner zone and alters the boiler heat absorption profile.[6] Effectiveness of this technique may range from 0-30 percent NO_x reduction depending on the type of boiler it is is applied to, and the fuel fired.

REDUCED COMBUSTION INTENSITY

Thermal NO_x formation can be controlled by reducing combustion intensity through load reduction (or derating) in existing units, and by enlarging the firebox in new units. The reduced heat release rate lowers the bulk gas temperature which in turn reduces thermal NO_x formation.[6]

Reduced firing rate often leads to several operating problems. Aside from limiting capacity, low load operation usually requires higher levels of excess air to maintain steam temperature and to control smoke and CO emissions. The steam temperature control range also is reduced substantially. This will reduce operating flexibility of the unit and its response to changes in load. The combined results are reduced operating efficiency due to higher excess air and a reduction in the system's load following capability due to a smaller control range.[6]

When the unit is designed for a reduced heat release rate, problems associated with derating are largely avoided. Use of an enlarged firebox produces NO_x reductions similar to load reduction on existing units.[6]

LOW NO_x BURNERS

Burner or combustor modification for NO_x control is applicable to all stationary combustion sources, except those without burners (spreader stoker coal boilers, for example). The specific design and configuration of a burner has an important bearing on the amount of NO_x formed. The main goal of low NO_x burners is to reduce the amount of NO_x formed to a minimum while achieving acceptable combustion of the fuel. Low NO_x burners are widely used on utility and industrial boilers, and employ LEA, OSC, or FGR principles. Control of NO_x formation in most low NO_x burners for utility boilers is achieved by reducing flame turbulence, delaying fuel/air mixing, and establishing fuel-rich zones where combustion initially takes place. The longer, less intense flames produced with low NO_x burners result in lower flame temperatures which reduce thermal NO_x generation. In addition, the reduced availability of oxygen in the initial combustion zone inhibits conversion of fuel-bound nitrogen to NO_x.[6]

Low NO_x burners typically are used as a NO_x emission control technique for process heaters, particularly on gas and oil fired refinery process heaters. These are generally staged air burners, which use the concepts of staged combustion to achieve NO_x reduction. The first stage incorporates firing a fuel-rich combustion mixture. The burner is designed to inject air after a sufficient time lag, to complete the combustion process. This technique reduces thermal NO_x formation by limiting the amount of excess air and reduces fuel NO_x by allowing enough time for reduction of fuel-bound nitrogen to N_2 in the reducing zone of the flame. NO_x reductions of around 55 percent are typical for these devices.[6] A number of designs based on the staged air principle are available for pulverized coal, and similar units are available for gas and oil boilers.

Other types of low NO_x burners include the staged fuel burner, the self-recirculating gasification (SRG) burner, and dual register burners. Staged fuel burners involve initial combustion of the fuel with high excess air followed by injection and combustion of the remaining fuel at low excess air. This technique allows initial combustion to occur at a relatively low temperature (1090°C, 2000°F), thus inhibiting thermal NO_x formation. As the combustion reaction goes to completion in the first zone, additional fuel is injected. The second reaction begins with a reduced partial pressure of oxygen which tends to limit formation of NO_x. The SRG burner involves use of flue gas recirculation, two-staged combustion, gasification reactions, and low excess air. The key design feature is creation of an exceptionally strong recirculation eddy at the burner throat which draws combustion reaction products from the furnace to gasify the fuel stream. Dual register burners have been included in some new boilers. Babcock and Wilcox is currently installing a dual register pulverized coal-fired burner in all its new large pulverized coal utility boilers. The B&W technique involves use of a limited turbulence, controlled diffusion flame burner. This minimizes fuel and air mixing at the burner to that required to obtain ignition and substain stable combustion of the coal. A venturi mixing device, located in the coal nozzle, provides a uniform coal/primary air mixture at the burner. Secondary air is introduced through two concentric zones surrounding the control nozzle. each of which is independently controlled by inner and outer air zone registers. Reductions in NO_x emissions have ranged from 40 to 60 percent due to this improved design. Foster Wheeler Energy Corporation also has developed a dual register coal burner in its new utility and industrial boilers. The new burner also reduces turbulence and causes controlled, gradual mixing of fuel and air at the burner. This is achieved using a dual throat with two registers which splits the secondary air into two concentric streams with independently variable swirl. Test results for this technique have realized NO_x reductions of 40 to 50 percent.[6]

FLUE GAS TREATMENT

The following two methods of NO_x reduction are flue gas treatment (FGT) techniques. FGT options may be either wet or dry processes. Wet processes are those which remove a pollutant in a solution or slurry from a wet scrubbing process. Dry processes are those which employ a spray of fine droplets of absorbing solution which mixes with the flue gas. Subsequent absorption of the pollutant occurs almost simultaneously with evaporation of the water in the droplet. Evaporation occurs due to the heat of the flue gas thus creating a dry powder. The FGT techniques considered here are dry processes, and both utilize NH_3 as a reducing agent. NH_3 is a selective reducing agent in that it selectively reduces NO_x without having to consume any excess O_2 first.

If NH_3 is injected after the boiler economizer; where temperature of the flue gas is about 370°C to 450°C, a catalyst is necessary. However, if NH_3 is injected into the secondary superheater region of the boiler, where the temperature of the flue gas approaches 980°C, a catalyst is not necessary. NH_3 reduction processes utilizing a catalyst are termed selective catalytic reduction (SCR) processes while those NH_3 reduction processes which operate without a catalyst are called selective non-catalytic processes (SNR), or simply ammonia injection.[6]

Selective Catalytic Reduction (SCR)

The SCR method is the more available FGT technique at this time. It is used commercially on over 60 gas- or oil-fired boilers and on two coal-fired boilers in Japan. The use of this process has been limited in the United States to a few pilot scale units on coal-fired boilers and a demonstration scale unit under construction on an oil-fired utility boiler.[6]

The chemical mechanisms used to reduce NO_x can be described by the following gas phase reactions

(1) $4NO + 4NH_3 + O_2 \qquad 4N_2 + 6H_2O$

(2) $2NO_2 + 4NH_3 + O_2 \qquad 3N_2 + 6H_2O$

Since most of the NO_x leaving the boiler is NO, the first reaction predominates.[6]

Flue gas from the economizer is mixed with vaporized ammonia prior to the reactor vessel. The gas then passes through the catalyst bed where the reduction process takes place. The flue gas subsequently exits the reactor and is sent to the air preheater and, if necessary, additional pollutant control devices.[6]

Problems associated with this technique primarily are involved with the catalyst and with the formation of solid ammonium sulfate ($(NH_4)_2SO_4$) and liquid ammonium bisulfate (NH_4HSO_4). For the combustion of sulfur containing fuels, catalysts must be chosen which are resistant to SO_x poisoning. Catalysts which fall into this category are oxides of titanium and vanadium. However, manufacturers will guarantee catalyst life only for one to two years in applications with high SO_x and particulate loadings. Particulates may "blind" the catalyst surface rendering it ineffective. $(NH_4)_2SO_4$ and NH_4SO_4 form when the proper conditions of temperature and SO_3 and NH_3 concentrations exist. The formation of these compounds is difficult to avoid since part of the NH_3 passes through the reactor unconsumed, and some catalysts promote the oxidation of SO_2 to SO_3. This problem may be alleviated by reheating the flue gas or by limiting NH_3 slip.[5]

Reactor designs are dependent on the type of fuel used in the combustion process. Gas-fired applications commonly use catalyst pellets in a fixed bed. Since the flue gas from oil- and coal-fired applications contains particulates, reactor designs usually incorporate honeycomb, pipe, or parallel plate shaped catalysts which allow the flue gas to pass in parallel along the catalyst surface. These configurations would limit the deposition of particulates on the catalyst.[6]

Extensive pilot plant and commercial plant data indicate that, for 90 percent NO_x removed, the ammonia to NO_x molar ratio is close to one. Ammonia feed control is essentially achieved by measuring the gas throughput and the NO_x concentration.[5]

Ammonia Injection

Ammonia injection, also known as selective noncatalytic reduction, was developed and patented by Exxon Research and Engineering Corporation under the trade name Thermal $DeNo_x$. Injection of NH_3 into the boiler at temperatures ranging from approximately 1070 K to 1290 K (1470°F to 1857°F) allows reduction of NO_x to N_2 without the need for a catalyst. However, optimal NO reduction occurs within a narrow temperature range, around 1240 ± 50 K (1770 ± 90°F). NO_x reductions on the order of 90 percent have been reported under well controlled laboratory conditions. This technique has been used in full-scale applications on gas- and oil-fired industrial boilers in Japan. However, their use is limited to emergency use during a photochemical smog alert or when total plant emissions exceed the regulation.[6] This technique has the following limitations:[4]

- Performance is very sensitive to flue gas temperature, and is maximized only within a 50K temperature gradient from the optimum temperature of about 1240K. This temperature sensitivity may require special procedures for load-following boilers.
- Performance is very sensitive to flue gas residence time at optimum temperatures. High flue gas quench rates are expected to reduce process performance.
- Costs of the process can be much higher than for other combustion controls.
- Successful retrofit application is highly dependent on the geometry of convective section.
- Byproduct emissions such as ammonium bisulfate might cause operational problems, especially in coal fired boilers.

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